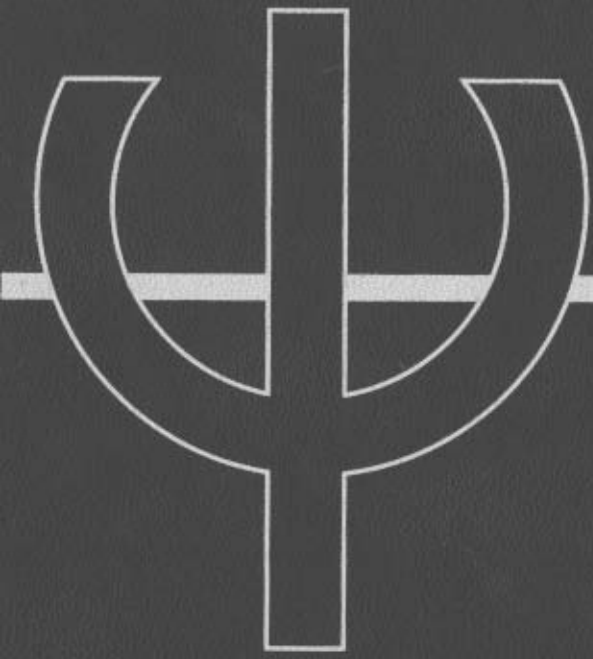

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TAKING THE FUNCTIONAL ASPECT OF MENTAL MODELS AS A STARTING POINT FOR STUDYING DISCOURSE COMPREHENSION*

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MENTAL MODELS IN DISCOURSE COMPREHENSION

The concept of mental models proposed by Johnson-Laird and his colleagues at the beginning of the 1980s (Johnson-Laird, 1983; Johnson-Laird and Garnham, 1980) stimulated a considerable amount of research in various fields of cognitive psychology. In the different fields, however, different aspects of the concept of mental models have been emphasized (see Johnson-Laird, 1989). In discourse-comprehension research the main emphasis has been on the structural aspect of mental models. Mental models are primarily characterized as being analogous in structure to the state of affairs they represent, as opposed to text-based representations, which are characterized as reflecting the propositional structure of a text. Based on this distinction, numerous studies of text comprehension and text memory were conducted during the 1980s in order to examine whether listeners/readers construct mental models. Nearly all of the studies were concerned with spatial information. This preference had mainly methodological reasons. It is

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relatively easy to construct texts in such a way that their propositional structure either corresponds to or, instead, differs from the spatial structure of the situation described in the texts. This renders it possible to test whether listeners/readers actually construct mental representations of what the text is about (i.e., mental models). The results of this research were encouraging: Several studies provided clear evidence for the construction of representations reflecting the structure of the described state of affairs rather than reflecting the propositional structure of the text (e.g., Ehrlich and Johnson-Laird, 1982; Garnham, 1981b; Glenberg *et al.*, 1987; Mani and Johnson-Laird, 1982; Morrow *et. al.*, 1987, 1989; Perrig and Kintsch, 1985; Wagener-Wender and Wender, 1990). Yet, in recent years the mental-model theory has gradually lost its stimulating force for text-comprehension research. More precisely, though many authors still consider the idea of mental models (or situation models)[1] important to a theory of discourse comprehension, fewer and fewer empirical studies are specifically inspired by the mental model theory. This development probably has two main causes: (1) A number of empirical results were reported showing that readers / listeners do not always construct mental models, which seems to speak against the mental-model theory. (2) It turned out to be difficult to derive interesting and empirically testable hypotheses from the theory with respect to the representation of non-spatial information. We think that the two issues have a common root. By concentrating on the "analogous-structure" hypothesis, the theoretical foundation of the idea of mental models fell into oblivion. In the present paper, we will try to show that it is worthwhile to recall the arguments that led to the idea of mental models. A clarification of the arguments renders it possible to decide whether the results referred to in (1) actually speak against the core assumptions of the mental-model theory or merely against certain propositions pertaining to the usual "reading" of the theory. It also helps to overcome the problem of stagnation addressed in (2), by indicating that important implications of the mental-model theory still lie fallow, awaiting their empirical tests.

We begin with a brief outline of the considerations that led to postulating the particular type of mental representation that is called a "mental model" (for a comprehensive discussion, see Johnson-Laird, 1983, 1989; Johnson-Laird *et al.*, 1984). After that we will turn to the two issues mentioned above.

FUNCTIONS OF MENTAL MODELS

The idea of mental models derived from considerations as to which ingredients a cognitive theory of discourse comprehension must have. The theory of mental models is founded on the tenet that

[1] The term *situation model* was introduced by van Dijk and Kintsch (1983). In their theory, situation models serve similar functions as are ascribed to mental models in Johnson-Laird's theory. In recent years the terms *mental model* and *situation model* have often been used synonymously, disregarding their different theoretical roots.

a theory of discourse comprehension must include propositions about non-linguistic representations, i.e., about representations of entities in the real or a fictitious world. There are two main reasons for this tenet, concerning (a) reference and (b) the relation between language comprehension and non-linguistic cognition. The respective considerations lead to postulating non-linguistic representations serving certain functions in discourse processing. These functions are of central importance for our topic. When it is clear which functions mental models are to serve, it is possible to spell out which properties mental models must necessarily have (and which properties they may have, but not necessarily so).

Reference. It is trivial to state that the entity that is referred to by a linguistic expression is not the same as the information contained in the expression. My dog is not the same as the information conveyed by the expression used for referring to that dog. In philosophy and linguistics the corresponding distinction is captured by the terms "meaning" and "sense", "reference" and "meaning", or "extension" and "intension", respectively. But what follows from this differentiation for a cognitive theory of language? It could be argued that referents, being entities in the world, are not subject of a cognitive theory of language. Thus, a cognitive theory of language must respect this distinction, but, with respect to the mind, is free to postulate just one kind of representations of meaning (called, for instance, "semantic" or "propositional" representations). However, as Johnson-Laird (1983, chap. 14) pointed out, such an approach is insufficient. Listeners/readers usually have little difficulties in interpreting referential expressions even when different expressions are used to refer to the same entity, or when in different clauses the same expression is used to refer to distinct entities. In order to give a full account of the cognitive mechanisms underlying reference resolution, it is necessary to distinguish between two levels of representation in the mind that are analogous to the distinction between intensional meaning and referent (see Figure 1).

Thus, in addition to semantic or propositional representations, which can be considered the internal counterpart of intensions, an additional type of representation has to be postulated for the internal counterpart of referents of linguistic expressions. A mental model is assumed to contain mental tokens standing for entities in the real or a fictitious world. Thus, a mental model represents the referents of linguistic expressions and therefore provides the basis for reference resolution. Providing the basis for reference resolution can be considered one of the main functions mental models serve in discourse comprehension.

Postulating a non-linguistic cognitive level at which the referents of discourse are represented is not unique to the theory of mental models, but is shared by many other cognitive theories of discourse comprehension – in psychology (e.g., van Dijk and Kintsch, 1983; Gernsbacher, 1990, 1997; Long *et al.*, 1997; Morrow, 1994; Sanford and Garrod, 1981; Zwaan and Radvansky, 1998), in linguistic semantics (e.g., Heim, 1982; Jackendoff, 1983, 1987; Kamp, 1981; Kamp and Reyle,

1993), and in artificial intelligence (e.g., Habel, 1986). In fact, within the framework of cognitive science, there seems to be no alternative to including such an additional level of representation in a theory of discourse processing.[2] For this reason it is clear that, even if there were empirical evidence against the mental-model theory, this should not lead to abandoning the idea of an non-linguistic representational level altogether. Rather, the more specific assumptions of the mental-model theory should be revised. The more specific assumptions concern the relation between mental models derived from text and mental representations involved in non-linguistic cognition. These assumptions also determine the second major function of mental models.

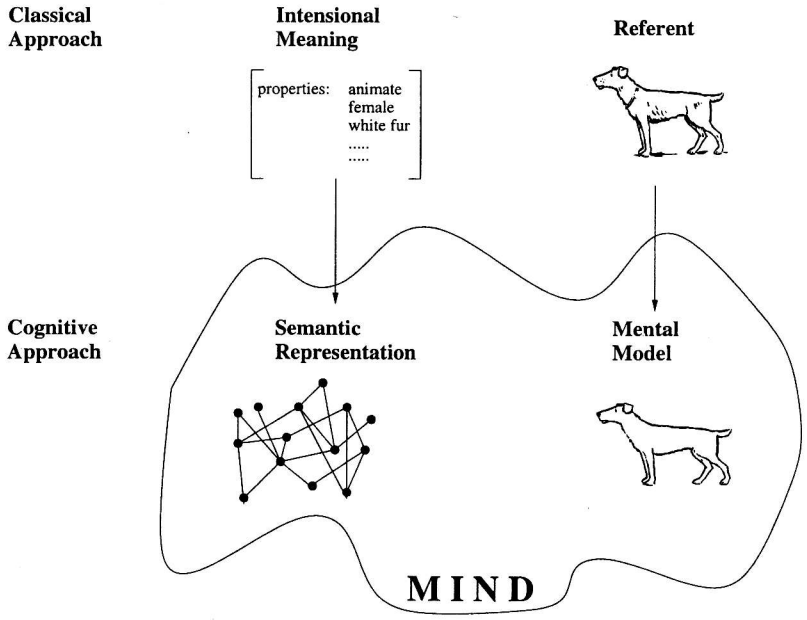

Figure 1. The two levels of representation analogous to the classical distinction between intensional meaning and the referent of the expression "my dog"

Relation between language comprehension and non-linguistic cognition. What does it mean to have understood an utterance? There is still no clear-cut answer to this question, and there probably never will be (Foertsch and Gernsbacher, 1994; Glenberg *et al.*, 1994). For example, selecting and integrating semantic representations to the effect of obtaining a representation of the text propositions and their structure can legitimately be considered as a form of text comprehension (e.g., McKoon and Ratcliff, 1992). However, when adopting a theory of only

[2] Interestingly, even McKoon and Ratcliff, the proponents of the minimalism hypothesis (McKoon and Ratcliff, 1992), propose a *discourse model* involving *conceptual entities* when they analyze processing of referential expressions (McKoon *et al.*, 1993).

these processes, one should be aware of its limitations. According to the considerations in the previous section, such a theory could only account for a shallow form of understanding, deficient with respect to reference resolution. Even if a theory does include a non-linguistic referential level of representation and therefore exhibits the properties needed to account for reference resolution, its scope may still be limited. Specifically, if the theory does not specify the relationship between the non-linguistic level and other non-linguistic cognitive subsystems, it cannot account for deeper understanding which involves drawing inferences based on world knowledge, as well as the ability to judge the truth of a statement. This is the case for most linguistic theories of discourse, as for instance, the Discourse-Representation Theory (Kamp, 1981; Kamp and Reyle, 1993) or the File-Change Semantics (Heim, 1982). In order to account for deep understanding, a theory has to specify how listeners/readers are able to connect information derived from linguistic input to their knowledge about the world and to their present perceptions. Of course, the non-linguistic referential level plays a central role here. Yet, there are two basically different possibilities of modeling the relationship between that level of representation and the "rest" of the human mind. First, it could be assumed that the non-linguistic referential level is exclusively used in language processing and that there are specific processes by which information can be transferred from there to the non-linguistic subsystems and in the reverse direction. Alternatively, it could be assumed that the non-linguistic referential representations are constructed in just that mental subsystem (or: those mental subsystems) in which the representations involved in non-linguistic cognition are given as well. Thus, according to this latter approach, there is a common representational "screen" for projecting the information derived from linguistic input, the information from perception, the information recalled from memory etc. This approach had been chosen by Johnson-Laird (1983) for the mental-model theory.[3] Johnson-Laird contends that a psychologically plausible theory of discourse comprehension has to explain how persons grasp and mentally represent the *extension* of sentences. "To understand a proposition is to know what the world would be like for it to be true." (Johnson-Laird, 1983, p. 155). Drawing on Possible-Worlds Semantics, he proposed that understanding an utterance means to construct a mental model that stands for the set of possible worlds in which the assertion would be true. Thus, mental models derived from linguistic input are of the same type as representations of the world derived from experience. Mental models derived from text are of the same format as mental representations that are constructed when directly experiencing, imagining or thinking of a state of affairs; they all are mental models. By virtue of this correspondence, the information from linguistic input can easily be amalgamated with information from other sources (e.g., memory,

[3] In recent years, Johnson-Laird (1996) seems instead to sympathize with the first mentioned approach, arguing that mental models are a specific kind of representation, differing not only from propositional representations, but also from mental images. His arguments mainly concern mental models in reasoning. We think that his former arguments (1983), favoring the second approach, are much more convincing. Moreover, turning away from the second approach would weaken the mental-model theory of discourse comprehension drastically (as will become clear in the last part of this paper).

current perception), giving rise to inferences during text comprehension. Also, mental models derived from linguistic input and other mental models can be juxtaposed so that the truth of an assertion can be judged, relative to the real or the hypothetical world under consideration. Hence, to represent the states of affairs described in a text in the same format as that used in non-linguistic cognition can be considered the second major function of mental models in discourse comprehension.

To summarize, mental models derived from text are ascribed two main interrelated functions: (a) providing a basis for interpreting referential expressions and (b) providing the cognitive representation of the extension of utterances, i.e., a representation of the real or fictitious world described. Accordingly, mental models derived from text can be characterized as referential representations, non-linguistic in nature, and, more precisely, as representations that are of the same type as those involved in directly experiencing or in thinking about a situation. Let us now consider the two critical issues mentioned above.

IMPLICATIONS FROM A FUNCTIONAL CHARACTERIZATION OF MENTAL MODELS

When are Mental Models Constructed?

There is wide agreement among the advocates of the mental-model approach that constructing mental models is not an automatic, but rather an active, attention-demanding process. This process is difficult or even impossible with certain kinds of texts (e.g., discontinuous or indeterminate texts), and generally poses problems for persons who lack the relevant background knowledge or do not possess sufficient working-memory capacity (for a review, see Long *et al.*, 1997; Morrow, 1994). However, experimental results have been reported which suggest that, even when being able to, readers do not always construct or use spatial mental models (Langston *et al.*, 1998; O'Brien and Albrecht, 1992; Wilson *et. al.*, 1993; de Vega, 1995; Zwaan and van Oostendorp, 1993, 1994). This apparently optional character of constructing and/or using mental models prompted serious criticism of the mental-model approach. Even authors who were basically sympathetic with this approach questioned the relevancy of the mental-model concept to text comprehension (e.g., Morrow, 1994; Zwaan and van Oostendorp, 1994).

However, when considering what the theory of mental models strictly implies, this reaction does not seem warranted. The theory claims that a mental model is indispensable for certain aspects of discourse comprehension: It is necessary for reference resolution and for deeper understanding

involving inferences based on world knowledge and the ability to judge the truth of the assertion. This only implies that *if* a person has understood a text in the sense just described, the person must have constructed a mental model. Thus, the mental-model approach cannot be challenged by the bare finding that readers/listeners dispense with mental-model construction under some experimental conditions. To challenge the theory, it would be necessary to additionally test for comprehension (in the sense described above) and to show that mental models were *not* constructed or used although the participant *did* understand the text segment under consideration. This was not shown by the above-mentioned studies.

Going slightly beyond what the theory of mental models strictly implies it could be assumed that the construction of mental models is not only necessary, but also sufficient for comprehension. In this case, we would expect a close correlation between mental-model construction and performance on comprehension tasks. The results by Zwaan and van Oostendorp (1994), that at first glance seem to weaken the mental-model approach, actually support this latter interpretation. Zwaan and van Oostendorp instructed participants either to read a story normally (once or twice) or to use an internal situation model when reading the text. Simply because they find differences between the groups of participants, the authors conclude that "people do not form integrated spatial representations ... during naturalistic text comprehension" (p. 110). However, the data indicate that the participants instructed to use a situation model significantly outperformed the other participants on the comprehension test, whereas reading a text twice (with normal reading instruction) had no effect. These results support the proposition that mental models are indeed relevant to discourse comprehension. A number of other empirical findings, too, can be interpreted as indicating that experimental conditions which can on theoretical or empirical grounds be assumed to promote the construction of mental models also benefit comprehension as assessed by verification tasks (Ehrlich and Johnson-Laird, 1982; Glenberg and Langston, 1992).

A second plausible hypothesis is that unless specific instructions are given, mental models are constructed only if the functions they serve (i.e., reference resolution, inferences, truth judgments) are necessary for mastering the task at hand. Results reported by Wilson *et al.* (1993), usually considered to pose a problem for the mental-model approach, now turn out to be consistent with the mental-model approach: In the experiments in which apparently no mental models were constructed, it was possible for the participants to cope with the task demands without even paying attention to the narrative (Wilson *et al.*, 1993, p. 149), whereas the experiments that did show evidence for the construction of mental models, involved trials that required verification of a described state of affairs (as to whether the protagonist and a particular object were in the same room or in different rooms). An analogous consideration applies to the modification of mental models. It is usually assumed that mental models are continuously updated during text processing. Yet, this hypothesis does not follow from the theory of mental models. The theory is perfectly compatible with the finding that a given property of the mental model is only updated when the

reader/listener "needs" this property for the current reference resolution or verification. De Vega (1995) found that participants at the time of reading about a location shift of the protagonist, did not update their mental model; however, updating *was* triggered when later on an ambiguous pronominal anaphor was encountered, the resolution of which required the consideration of the new surroundings of the protagonist. Clearly, this result does not speak against the mental-model theory – on the contrary, it fits nicely into the considerations presented here.

Taken together, it cannot be deduced from the theory of mental models that mental models are routinely constructed whenever the person is able to do so. Rather, if we assume the functional characterization of mental models, then the relationship between constructing mental models and comprehension becomes crucial. Findings indicating that mental models are not constructed under certain experimental conditions do not challenge the mental-model account as long as a parallel pattern is found for comprehension data. Moreover, the particular experimental results mentioned above, which at first glance seem to weaken the mental-model approach, turn out to be well compatible with the approach. In fact, they underscore the close link between constructing mental models and comprehending. It is a task for future research to investigate this link more thoroughly. A methodological approach similar to the "three-pronged method" advocated by Graesser, Trabasso and others may be particularly useful here, which assesses discourse comprehension on various dimensions (cf. Graesser *et al.,* 1994; Magliano and Graesser, 1991; Zwaan and Brown, 1996).

What Mental Models are *Not*

The question as to when spatial mental models are constructed is part of the broader question of what information is included in a mental model, and under what conditions. Some opponents of the mental-model approach, for instance McKoon and Ratcliff (1992), took a mental model as "a full representation of the real-life situation" (1992, p. 458). This conception is akin to the "pictures-in-the-head" conception of mental images (Dennett, 1969), assuming that a non-propositional representation has to be fully specified. However, the imagery debate has shown that this assumption is not warranted. Mental images do have the option to be noncommittal to some details (cf. Block, 1983; Kosslyn, 1980). More generally, mental images cannot be assumed to exhibit the properties of stimuli, but rather the properties of percepts, i.e., of mental representations created when perceiving the stimuli. Similarly, the theory of mental models does not claim that the mental models derived from text have the properties of states of affairs, but rather to have the properties of the mental representations that are created when perceiving, imagining or thinking of a state of affairs. The representations created when thinking of or imagining situations are surely not fully-specified representations of situations. Nor is it likely that the representations constructed during perception are fully specified, given the evidence from

research on visual attention. Hence, it is inadequate to suggest that mental models derived from text are fully-specified real-life like representations (see also Glenberg and Mathew, 1992; Glenberg *et al.*, 1994; Johnson-Laird, 1983; Oakhill *et al.*, 1989).

This conclusion is important, but has the disadvantage of being a negative statement. It does not allow us to derive positive hypotheses about what information a mental model contains, and under what conditions. This may be one of the reasons why past research on mental models primarily focussed on the structural characterization of mental models. Unfortunately, however, this characterization of mental models is dubious. Johnson-Laird (1983) wrote: "The structures of mental models are identical to the structures of the states of affairs, whether perceived or conceived, that the models represent" (Johnson-Laird, 1983, p. 419). This admittedly ambiguous statement seems to have given rise to a momentous misunderstanding, namely that mental models derived from text are analogous in structure to the *real* situation they represent. This conception of "analogous", however, is problematic for various reasons. First and most importantly, it does not fit well the central idea of Johnson-Laird's theory of mental models. As we pointed out before, the central idea is that mental models derived from text are of the same type as the representations constructed when experiencing or thinking of a situation. Unless these representations are assumed to be analogous representations of real situations, mental models derived from text cannot be assumed to be analogous representations of real situations. Moreover, mental models represent several different properties of states of affairs (spatial location, color, size etc.). Is the statement that a mental model is an analogous representation of the real situation meant to hold for each of those properties? When considering which properties of a situation may plausibly be represented analogously, the limited value of this conception of "analogous representations" becomes evident. If at all, the proposition seems plausible for spatial and temporal relations, but even here certain characteristics of the representations are hardly compatible with it (for instance, the 2- or $2^1/_2$-D character of spatial representations in contrast to the 3-D character of the real situation). For other relations, such as causal relations or means-end relations, it is unclear what an analogous representation of the real situation might be, and for still other aspects the question is meaningless. For instance, since emotions are not an aspect of real situations (but rather of experiencing situations), it does not make sense to ask whether emotions described in a text are represented analogously to the real situation.

In contrast, when mental models are conceived of as representations that are of the same type as representations constructed in non-linguistic cognition, a different conception of "analogous" becomes appropriate. According to this conception, a mental model derived from a text has the same structure as the representations constructed when perceiving or conceiving the corresponding situation. With such an alternative conception of "analogous" none of the above mentioned problems arise.

After having dwelled on what mental models are *not*, let us now try to arrive at positive statements about mental models. We begin with a brief summary of research concerning the principles that guide the selection of information to be represented in a mental model. With respect to these principles, the mental-model theory does not differ significantly from most other theories of text comprehension that involve a referential level of representation. We shall then examine the implications of the more specific claim that mental models derived from text are of the same type as the representations employed in non-linguistic cognition.

Represented Entities and Represented Variables

Corresponding to the functional characterization of mental models, we may first ask which entities are represented in a mental model. The selection is surely not arbitrary, but follows certain principles. Such a principle, which defines the selection of entities represented in a given mental model, will be called an "ensemble-defining variable". Note that a given selection may be based on more than one ensemble-defining variable.

One ensemble-defining variable that is certainly important in discourse comprehension is "mentioning": Entities explicitly mentioned in the text are likely to be included in the mental model; this may be influenced by the particular referential expression (Garrod *et al.*, 1994; Sanford and Garrod, 1981) or the linguistic form of the sentence (Caramazza *et al.*, 1977; McKoon *et al.*, 1993; see also Oakhill *et al.*, 1989). It is reasonable to assume, however, that mentioning is of different importance for different kinds of texts: Considering the functions of mental models, in particular for reference assignment, it is conceivable that listeners/readers tend to represent and keep available mainly such entities that can be expected to be referred to in the forthcoming text segment. Including primarily entities explicitly mentioned in the text is reasonable if the listener / reader does not have available sufficient background knowledge for forming specific expectations, as is the case with many expository texts. In contrast, with narrative texts, general world knowledge and knowledge about the typical structure of stories often allows for forming specific expectations, which then control the selection of entities to be encoded in the mental model. This means that other variables gain relevance as ensemble-defining variables. The entities primarily included in the model are related to the goal of the protagonist (e.g., Albrecht *et al.*, 1995; Graesser *et al.*, 1994; Morrow *et al.*, 1989), in the "here and now of the protagonist" (e.g., Carreiras *et al.*, 1997; Glenberg *et al.*, 1987; Morrow *et al.*, 1987, 1990; Rinck and Bower, 1995; Zwaan, 1996), and causally related to the described event (for a review, see van den Broek, 1994).

The representation of referents and potential referents is only one part of the information contained in a mental model. The other part are the entities' properties and interrelations. These

one- or many-place relations that are represented in a particular mental model will be called "represented variables". Ensemble-defining variables and represented variables *may* concern the same aspects of the state of affairs the text is about, but they need not do so. For instance, data by Morrow *et al.* (1989) can be interpreted as indicating that only entities related to the goal of the protagonist are represented in the mental model (= goal-relatedness is an ensemble-defining variable), but that within the mental model the spatial relations among those entities are represented (= spatial relations are a represented variable). We certainly do not claim that mental models for narrative texts generally have this particular "design"; the point we want to stress is that two kinds of variables have to be distinguished theoretically, one that concerns the entities that are represented and one that concerns the represented information about these entities.

An interesting question is whether for a given represented variable the values of *all* entities encoded in the model must be specified.[4] Or is it possible, for instance, that the colour of the protagonist's coat is represented, but not the colour of his scarf?

Analogous to what has been said about the selection of entities to be represented in a model, it may be assumed that properties and interrelations explicitly mentioned in the text are especially likely to be encoded. However, some qualifications are in order: First, as was already pointed out, not all of what is explicitly mentioned in the text must necessarily be encoded (see also Oakhill *et al.,* 1989). Second, the syntactic function (e.g., attributive vs. predicative use) may have an impact on the likeliness of encoding (Rothkopf *et al.,* 1986, 1988, cit. in McKoon *et al.*, 1993, p.59). And last but not least, inferred properties and relations may become more important than explicitly mentioned ones depending on the conceptual knowledge about the entities referred to (e.g., Garnham 1981a; Garrod and Sanford, 1990; see also Keenan, 1993), as well as depending on the demands of the particular experimental task.

However, the selection of represented variables may not always be "tailor-made" for the particular task at hand. There may be variables that are represented by default. For instance, Glenberg and Langston (1992), assuming that discourse entities are represented in the Visuo-Spatial Sketchpad (Baddeley, 1986), propose that spatial relations are encoded by default. On the other hand, Zwaan and van Oostendorp (1994; see also Zwaan and Graesser, 1993) emphasize that spatial information is incorporated only if it is causally relevant. Most studies that provided evidence for the representation of spatial information involved expository texts on spatial arrangements,

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[4] If it is assumed that a mental model is an integrated representation combining different kinds of information about the encoded entities, this issue is interesting but without further consequences for the theory. However, a mental model can also be conceived of as a grouping of representations. Each kind of information (e.g., color) is represented in a separate mental subsystem, i.e., each subsystem represents one specific variable. In this case, the issue is associated with the question as to whether the various subsystems may use different ensemble-defining variables for entity selection.

employed experimental tasks emphasizing spatial information, or had the participants informed about the spatial layout nonverbally prior to the text (e.g., Denis and Zimmer, 1992; Franklin *et al.*, 1992; Mani and Johnson-Laird, 1982; Morrow *et al.*, 1987, 1989; Perrig and Kintsch, 1985; Radvansky *et al.*, 1993; Rinck and Bower, 1995; Rinck *et al.*, 1997; Wagener-Wender and Wender, 1990). Clearly, these studies are not suited to resolve whether this variable is represented by default or whether spatial information is encoded during text comprehension only if this information is accentuated. However, the former view is supported by a few studies suggesting that spatial information is encoded even under more naturalistic reading conditions and with texts in which this kind of information is not emphasized (Black *et al.*, 1979; Glenberg *et al.*, 1987).

Drawing on Research in Non-Linguistic Cognition

If it is true that during text comprehension representations are created which are of the same kind as the representations derived from direct experience, research on nonverbal cognition, as well as research on emotions and motivation, is of direct relevance to discourse comprehension research. Theoretical and empirical findings from those fields of research can be utilized in order to arrive at promising hypotheses on the properties of mental models derived from text.

Although situations are experienced as integrated wholes, the various aspects associated with a situation (e.g., visual, auditory, tactile, emotional...) are processed in different mental subsystems, and it is unlikely that there is an additional distinct amodal subsytem that integrates the information (cf. Barsalou, in press). Consequently, a mental model cannot be conceived of as one integrated representation, but rather as a grouping of representations each of which is supported by a distinct mental subsystem. Accordingly, empirical investigations of the properties of mental models must be done separately for the different aspects.

Equivalent effects. One of the questions that can be posed for each aspect is whether equivalent effects obtain in text comprehension and non-linguistic cognition. More specifically, does the experimental manipulation of a particular aspect of a situation produce analogous effects when the person is reading or listening to a text describing the situation as when the person experiences the situation or imagines the situation? Of course, not all variables can be expected to have equivalent effects in different domains, since linguistic and non-linguistic stimuli are processed in different subsystems at the early stages, and, in addition, may differ in the amount of information they provide. Hence, of special interest are those effects in non-linguistic cognition that arise from the particular properties of the representational subsystem. The spatial distance effect in scanning mental images may serve as an example. This effect is usually attributed to the properties of the representational subsystem, the Visuo-Spatial Sketchpad in Baddeley's theory (1986) or the Visual Buffer with its Attention Window in Kosslyn's theory (1994), respectively.

Finding a corresponding distance effect on anaphoric reference resolution during discourse comprehension would strengthen the hypothesis that this mental subsystem is involved in discourse comprehension as well. As is well known from the literature on discourse processing, such a distance effect was actually observed in several studies (e.g., Glenberg *et al.,* 1987; Morrow *et al.,* 1990; Rinck and Bower, 1995), although these studies were not designed to test the particular hypothesis presented here. Drawing on mental imagery research, however, also leads to *new* predictions in text-comprehension research. Let us consider some examples.

Research concerned with Kosslyn's theory (1980, 1994) suggest that visual-spatial representations are dense and that the Visual Buffer has limited size and resolution. Hence, if it is true that the spatial component of a mental model is given in the same representational medium as visual-spatial images, a mental model must be assumed to represent a connected portion of the perceived or a conceived world. More precisely, it covers a particular interval of the represented variable (spatial location of entities). This does not mean that within the interval each value of the variable is actually occupied by a token, but merely that the model is especially well "prepared" to encode entities that are located within this interval. Thus, it can be predicted that reading times are shorter, when the text introduces a new entity that is within the interval than when it introduces a new entity that is outside that interval. Note that this prediction marks a difference to propositional representations, in which entities can be included equally well independent of their location[5]. This example leads us to another question. Given that the representational system is fixed in size and resolution, how is it possible that we are able to create representations of extended states of affairs such as a described route through our home town to a newly opened French restaurant, as well as to create adequate representations of minutely described states of affairs such as the nice layout of the restaurant's menu? Drawing on Kosslyn's theory, the answer is *zooming*. Although the Visual Buffer is fixed in size and resolution, the size of the spatial interval that is mapped onto it is variable, as is the granularity level. Either the size of the interval or the granularity level can be chosen according to the task demands, with the other one then being automatically defined. Thus, size of represented interval and granularity level are related reciprocally. If the represented interval is small, fine discriminations with respect to spatial location are possible. The problem with a small interval is that, when in a following text segment an entity is introduced which is located outside the interval, the model is not prepared to represent this entity and the interval has to be shifted or enlarged. The problem with a large interval is that only coarse discriminations can be achieved. As a consequence, entities that are very close to each

[5] The principle can be generalized to other domains, giving a novel criterion of differentiating between structurally analogous and propositional representations: In contrast to propositional representations, structurally analogous representations do not allow for choosing ensemble-defining and represented variables fully independently of each other: If X is a represented variable and X is represented analogously, entities having values on X that lie within the represented interval are easily included in the representation, whereas entities with values outside the interval can be entered into the representation only if appropriate modifications concerning the represented variable are made.

other may be indistinguishable in the representation. When an upcoming text segment (or an experimental test) requires the reader to discriminate between these entities' locations, the size of the represented interval must be reduced in order to improve resolution. It is reasonable to assume that changing the size of interval and the granularity level is strenuous and takes time. Thus, text difficulty can be predicted to depend on how often the text calls for such changes. In addition, decreasing the interval may have the consequence that entities with extreme values drop out of the mental model. Accordingly, we can predict that an entity becomes less accessible for anaphor resolution or probe recognition when a text shifts from the description of a whole situation to the description of a detail in a region that does not include the entity. We tested this prediction in a series of experiments, employing the probe-recognition method for assessing the accessibility of the target entity. Participants were presented with 20 narrative texts of the type illustrated in Table 1. The two versions of a text differed in only one sentence. In one version ("Out of Scope"), this sentence focussed on a detail far away from the critical entity. In the other version ("In Scope"), the sentence referred to the whole situation or to a part of it that, when viewed from the perspective of the protagonist, included the critical entity. The results of the studies were in line with the prediction: Probe-recognition times were longer with the version "Out of Scope" than with the version "In Scope".

Table 1. Sample story of the experiments on granularity level and scope of mental models.

Heading	Painting Outside
Setting	Fabian promised his girlfriend that he would paint her a picture while he was on vacation. It's now the last day of his vacation and he hasn't been very successful. So he sets off early in the morning with his easel and painting supplies. As usual, he takes the path through the field. At a curve in the path he stops, looks around, and considers what else he can paint.
Introduction of Critical Entity	He has already tried, unsuccessfully, to paint the *barn* in the cornfield.
Variation	
Version 'In Scope'	This time he notices the pretty color of the mountains in the background.
Version 'Out of Scope'	This time he notices the pretty color of a violet growing near the path.
Final Sentence	Fabian gazes with pleasure upon his new painting theme.
Probe	barn

Note. In the texts presented to the subjects the critical entity was not emphasized.

Amalgamation and Interference. A second approach is to investigate whether interaction effects obtain from the environment the reader / listener is actually situated in and the situation portrayed by the text. Finding that a particular property of the actual situation (e.g., temperature of the room) influences the processing of text information concerning the same feature dimension of a fictitious situation, or vice versa, supports the hypothesis that the same mental subsystem is used in the two domains. An example for an interaction of this kind can be found in research on emotions: The mood of the reader/listener influences the way linguistic information about the mood of the protagonist of a narrative is processed (Teasdale, 1993). There is also some experimental support for the complementary case, in which linguistic information influences the emotions of the reader, be it because of identification with the protagonist or because of feeling as a witness (cf. Oatley, 1992; Tan, 1994). Moreover, this type of interaction is well-known from everyday-life experience: When reading about Rhett Butler leaving Scarlet we cry, and when reading an exciting thriller in our bedroom at night we are scared. Considering these examples, it seems fruitful to further investigate the hypothesis that linguistically conveyed information and the information from the reading/listening situation are represented in the same mental subsystems and are therefore amalgamated.

It is likely that sometimes the information from the different sources, albeit pertaining to the same feature dimension, is so heterogeneous that amalgamation is impossible. If processing of the actual situation has priority, the reader/listener should then have difficulties in properly understanding the text information pertaining to this dimension. This global proposition can be spelled out for various kinds of information. We will consider only one issue, which concerns a topic that has so far not received the attention it deserves, namely the difference between reading and listening. One of the differences between reading and listening is that reading requires eye movements, which in turn require information about the spatial properties of the printed text. Although it is not yet clear precisely which mental subsystems are engaged in encoding and representing this spatial information it is conceivable that this task draws on the visual-spatial subsystem referred to before. If this is the case, the reader should encounter difficulties in understanding text information concerning visual-spatial aspects of the described situation. In contrast, listening to a text does not constitute such a "dual-task"-situation (with respect to spatial information processing), and therefore allows the visual-spatial text information to be represented in the visual-spatial subsystem without interference. There are some experimental results that bolster this hypothesis (Baddeley, 1986; Glass *et al.*, 1985; Peterson *et al.*, 1977). In order to test the hypothesis more directly, we varied the text modality in the above mentioned series of experiments. Half of the participants listened to the texts, presented via loudspeakers. The other participants read the texts, presented on the computer screen (sentence by sentence). If reading indeed hampers constructing the spatial component of mental models, the "In-Out"-effect mentioned above should be attenuated in the "reading"-group, since the effect depends on a spatial mental model. The results of the experiments corresponded to our expectations: Under the

listening condition a significant "In-Out"-effect was observed in all our experiments. Under the reading condition, however, the effect was numerically smaller and sometimes not even significant. This supports the hypothesis that spatial information derived from texts is represented in the mental subsystem which provides the basis for the control of eye-movements.

CONCLUSIONS

Ironically, the characteristic of mental models that initially made the theory so attractive, namely their analogous character, became the theory's nemesis. Because research focussed on this characterization of mental models, the theoretical construct of mental models became impoverished. Moreover, the characterization led to the dubious hypothesis that mental models are structurally analogous to the state of affairs described by the text. The mental-model theory will probably soon no longer play an important role in research, unless effort is made to further develop the theory. The present paper is a first step in this direction. Resuming some of the arguments that originally motivated the mental-model theory of discourse comprehension, we tried to overcome two problems that dimish the attractiveness of the theory. Both problems are mainly due to misunderstandings. First, the theory does not claim that listeners/readers construct mental models whenever they are able to, but rather that deep understanding consists in constructing a mental model. Obviously, more empirical studies are needed, in particular to examine the relationship between comprehension and the construction of a mental model in detail. Second, a central assumption of the theory is that mental models derived from text stand for the worlds in which the text would be true. This assumption does *not* imply that mental models derived from text are analogous to *real* states of affairs; it rather implies that they are of the same type as the mental representations constructed in non-linguistic cognition, for instance, when thinking of or perceiving a state of affairs. When mental models derived from text are characterized in this way, it becomes clear that discourse-comprehension research should consider the results of research on non-linguistic cognition in order to arrive at promising hypotheses. Research could be directed either at the equivalence of effects in the different domains or at interaction effects. We have presented some examples for both approaches, but there are numerous other interesting topics that we have left unmentioned.

REFERENCES

Albrecht, J. E., E. J. O'Brien, R. A. Mason and J. L. Myers (1995). The role of perspective in the accessibility of goals during reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **21**, 364-372.

Baddeley, A. (1986). *Working memory*. Clarendon Press, Oxford.

Barsalou, L. (in press). Perceptual symbol systems. *Behavioral and Brain Sciences*.

Black, J. B., T. J. Turner and G. H. Bower (1979). Point of view in narrative comprehension, memory, and production. *Journal of Verbal Learning and Verbal Behavior*, **18**, 187-198.

Block, N. (1983). The photographic fallacy in the debate about mental imagery. *Noûs*, **17**, 651-661.

van den Broek, P. (1994). Comprehension and memory of narrative texts: inferences and coherence. In: *Handbook of psycholinguistics* (M. A. Gernsbacher, ed.), pp. 539-607. Academic Press, San Diego.

Caramazza, A., E. Grober, C. Garvey and J. Yates (1977). Comprehension of anaphoric pronouns. *Journal of Verbal Learning and Verbal Behavior*, **16**, 601-609.

Carreiras, M., N. Carriedo, M. A. Alonso and A. Fernandez (1997). The role of verb tense and verb aspect in the foregrounding of information during reading. *Memory & Cognition*, **25**, 438-446.

Denis, M. and H. D. Zimmer (1992). Analog properties of cognitive maps constructed from verbal descriptions. *Psychological Research*, **54**, 286-298.

Dennett, D. C. (1969). The nature of images and the introspective trap. In: *Content and consciousness* (D. C. Dennett, ed.), pp. 132-141. Routledge and Kegan Paul, London.

van Dijk, T. A. and W. Kintsch (1983). *Strategies of discourse comprehension*. Academic Press, New York.

Ehrlich, K. and P. N. Johnson-Laird (1982). Spatial descriptions and referential continuity. *Journal of Verbal Learning and Verbal Behavior*, **21**, 296-306.

Foertsch, J. and M. A. Gernsbacher (1994). In search of complete comprehension: Getting "Minimalists to work", *Discourse Processes*, **18**, 271-296.

Franklin, N., B. Tversky and V. Coon (1992). Switching points of view in spatial mental models. *Memory & Cognition*, **20**, 507-518.

Garnham, A. (1981a). Anaphoric references to instances, instantiated and non-instantiated categories: A reading time study. *British Journal of Psychology*, **72**, 377-384.

Garnham, A. (1981b). Mental models as representations of text. *Memory & Cognition*, **9**, 560-565.

Garrod, S. C., D. Freudenthal and E. Boyle (1994). The role of different types of anaphor in the on-line resolution of sentences in a discoruse. *Journal of Memory and Language*, **33**, 39-68.

Garrod, S. C. and A. J. Sanford (1990). Referential processes in reading: Focusing on roles and individuals. In: *Comprehension processes in reading* (D. A. Balota, G. B. Flores d'Arcais and K. Rayner, eds.), pp. 465-485. Erlbaum, Hillsdale, NJ.

Gernsbacher, M. A. (1990). *Language comprehension as structure building*. Erlbaum, Hillsdale, NJ.

Gernsbacher, M. A. (1997). Two decades of structure building. *Discourse Processes*, **23**, 265-304

Glass, A. L., D. R. Millen, L. G. Beck and J. K. Eddy (1985). Representation of images in sentence verification. *Journal of Memory and Language*, **24**, 442-465.

Glenberg, A. M., P. Kruley and W. E. Langston (1994). Analogical processes in comprehension: Simulation of a mental model. In: *Handbook of psycholinguistics* (M. A. Gernsbacher, ed.), pp. 609-640. Academic Press, New York.

Glenberg, A. M. and W. E. Langston (1992). Comprehension of illustrated text: Pictures help to build mental models. *Journal of Memory and Language*, **31**, 129-151.

Glenberg, A. M. and S. Mathew (1992). When minimalism is not enough: Mental models in reading comprehension. *PSYCOLOQUY*, reading-inference.

Glenberg, A. M., M. Meyer and K. Lindem (1987). Mental models contribute to foregrounding during text comprehension. *Journal of Memory and Language*, **26**, 69-83.

Graesser, A. C., M. Singer and T. Trabasso (1994). Constructing inferences during narrative text comprehension. *Psychological Review*, **101**, 371-395.

Habel, C. (1986). *Prinzipien der Referenzialität*. Springer, Berlin.

Heim, I. (1982). *The semantics of definite and indefinite noun phrases*. Ph.D. dissertation, University of Amherst (distributed by SFB 99, Univ. Konstanz).

Jackendoff, R. (1983). *Semantics and cognition*. MIT Press, Cambridge, MA.

Jackendoff, R. (1987). *Consciousness and the computational mind*. MIT Press, Cambridge, MA.

Johnson-Laird, P. N. (1983). *Mental models*. Cambridge University Press, Cambridge.

Johnson-Laird, P. N. (1989). Mental models. In: *Foundations of cognitive science* (M. I. Posner, ed.), pp. 469-499. MIT Press, Cambridge, MA.

Johnson-Laird, P. N. (1996). Images, models, and propositional representations. In: *Models of visuospatial cognition* (M. de Vega, M. J. Intons-Peterson, P. N. Johnson-Laird, M. Denis and M. Marschark, eds.), pp. 90-127. Oxford University Press, Oxford.

Johnson-Laird, P. N. and A. Garnham (1980). Descriptions and discourse models. *Linguistics and Philosophy*, **3**, 371-393.

Johnson-Laird, P. N, D. J. Herrmann and R. Chaffin (1984). Only connections: A critique of semantic networks. *Psychological Bulletin*, **96**, 292-315.

Kamp, H. (1981). A theory of truth and semantic representation. In: *Formal methods in the study of language* (J. Groenendijk, T. Janssen, and M. Stokhof, eds.), part 1, pp. 277-322. Mathematisch Centrum, Amsterdam.

Kamp, H. and U. Reyle (1993). *From discourse to logic*. Kluwer, Dordrecht.

Keenan, J. M. (1993). Thoughts about the minimalist hypothesis. *PSYCOLOQUY*, reading-inference.

Kosslyn, S. M. (1980). *Image and mind.* Harvard University Press, Cambridge, MA.

Kosslyn, S. M. (1994). *Image and brain.* MIT Press, Cambridge, MA.

Langston, W., D. C. Kramer and A. M. Glenberg (1998). The representation of space of mental models derived from text. *Memory & Cognition*, **26**, 246-262.

Long, D. L., B. J. Oppy and M. R. Seely (1997). Individual differences in readers' sentence- and text-level representations. *Journal of Memory and Language*, **36**, 129-145.

Magliano, J. P. and A. C. Graesser (1991). A three-pronged method for studying inference generation in literary text. *Poetics*, **20**, 193-232.

Mani, K. and P. N. Johnson-Laird (1982). The mental representation of spatial descriptions. *Memory & Cognition*, **10**, 181-187.

McKoon, G. and R. Ratcliff (1992). Inference during reading. *Psychological Review*, **99**, 440-466.

McKoon, G., G. Wald, R. Ratcliff and R. Spoart (1993). Morphosyntactic and pragmatic factors affecting the accessibility of discourse entities. *Journal of Memory and Language*, **32**, 56-75.

Morrow, D. G. (1994). Spatial models created from text. In: *Naturalistic text comprehension* (H. van Oostendorp and R. A. Zwaan, eds.), pp. 57-78. Ablex, Norwood.

Morrow, D. G., G. H. Bower and S. L. Greenspan (1989). Updating situation models during narrative comprehension. *Journal of Memory and Language*, **28**, 292-312.

Morrow, D. G., G. H. Bower and S. L. Greenspan (1990). Situation-based inferences during narrative comprehension. In: *The psychology of learning and motivation*, (A. C. Graesser and G. H. Bower, eds.), Vol. 25: Inferences and text comprehension, pp. 123-135. Academic Press, San Diego, CA.

Morrow, D. G., S. L. Greenspan and G. H. Bower (1987). Accessibility and situation models in narrative comprehension. *Journal of Memory and Language*, **26**, 165-187.

Oakhill, J., A. Garnham and W. Vonk (1989). The on-line construction of discourse models. *Language and Cognitive Processes*, **4**, 263-286.

Oatley, K. (1992). *Best laid schemes: The psychology of emotion.* Cambridge University Press, Cambridge.

O'Brien, E. J. and J. E. Albrecht (1992). Comprehension strategies in the development of a mental model. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **18**, 777-784.

Perrig, W. and W. Kintsch (1985). Propositional and situational representations of text. *Journal of Memory and Language*, **24**, 503-518.

Peterson, M. J., J. E. Thomas and H. Johnson (1977). Imagery, rehearsal, and the compatibility of input-output tasks. *Memory & Cognition*, **5**, 415-422.

Radvansky, G. A., D. H. Spieler and R. T. Zacks (1993). Mental model organization. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **19**, 95-114.

Rinck, M. and G. Bower (1995). Anaphora resoulution and the focus of attention in situation models. *Journal of Memory and Language*, **34**, 110-131.

Rinck, M., A. Hähnel, G. Bower and U. Glowalla (1997). The metrics of spational situation models. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **23**, 622-637.

Rothkopf, E., B. Biesenbach and M. Billington (1986). *Syntax violations as error feedback during rapid reading: Suggestions for a new readability measure supplement.* (Technical memorandum). AT & T Bell Laboratories.

Rothkopf, E., M. Koether and M. Billington (1988). *Why are certain sentence constructions mnemonically robust for modfiers?* (Technical memorandum). AT & T Bell Laboratories.

Sanford, A. J. and S. C. Garrod (1981). *Understanding written language*. Wiley, Chichester.

Tan, E. S. (1994). Story processing as an emotion episode. In: *Naturalistic text comprehension* (H. van Oostendorp and R. A. Zwaan, eds.), pp. 165-188. Ablex Norwood, NJ.

Teasdale, J. D. (1993). Selected effects of emotion on information-processing. In: Attention: selection, awareness and control (A. Baddeley and L. Weisskrantz, eds.), pp. 374-389. Clarendon Press, Oxford.

de Vega, M. (1995). Backward updating of mental models during continuous reading of narratives. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **21**, 373-385.

Wagener-Wender, M. and K. F. Wender (1990). Expectations, mental representations, and spatial inferences. (A. C. Graesser and G. H. Bower, eds.), Vol. 25: Inferences and text comprehension, pp. 137-157. Academic Press, San Diego, CA.

Wilson, S. G., M. Rinck, T. P. McNamara, G. H. Bower and D. G. Morrow (1993). Mental models and narrative comprehension: some qualification. *Journal of Memory and Language*, **32**, 141-154.

Zwaan, R. A. (1996). Processing narrative time shifts. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **22**, 1196-1207.

Zwaan, R. A. and C. M. Brown (1996). The influence of language proficiency and comprehension skill on situation-model construction. *Discourse Processes*, **21**, 289-327.

Zwaan, R. A. and A. C. Graesser (1993). Reading goals and situation models. *PSYCOLOQUY*, reading-inference.

Zwaan, R. A. and H. van Oostendorp (1993). Do readers construct spatial representations during naturalistic story comprehension. *Discourse Processes*, **16**, 125-143.

Zwaan, R. A. and H. van Oostendorp (1994). Spatial information and naturalisitc story comprehension. In: *Naturalistic Text Comprehension* (H. van Oostendorp and R. A. Zwaan, eds.), pp. 97-114. Ablex, Norwood.

Zwaan, R. A. and G. A. Radvansky (1998). Situation models in language comprehension and memory. *Psychological Bulletin*, **123**, 162-185.

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