MENTAL REPRESENTATION OF SPATIAL INFORMATION: A PRODUCTION SYSTEM MODEL FOR PRIMING AND VERIFICATION

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ABSTRACT

In this contribution we investigate the mental representation of spatial information. In a previous paper (Wender & Wagener, 1985) we reported results that supported the idea of spatial information being mentally represented in an analogue format. This paper extends the previous results. Furthermore a simulation model is developed that describes the data from two different experimental tasks, a priming technique and a sentence verification test. These experimental tasks gave results that in part look contradictory. The model discussed is an attempt to account for this contradiction.

INTRODUCTION

The format of mental representations has been under discussion for several years now. We don´t want to review this discussion. Our basic opinion is that propositional as well as analogue representations are possible. To some extent the format may be under the control of the person. Furthermore, the form of the representation and the processes working upon it interact. This interaction may also contain a tradeoff between building efforts and processing times. If a person expects a spatial task involving spatial judgments probably a spatial representation is formed which may cost more effort. If a person expects a more abstract task then a propositional representation may be preferred. Also, a person may be able to change the representation if the type of the task requires this.

The mental representation of spatial information is investigated in this paper by a priming technique and a sentence verification test. Both methods consider the relationship between decision times and spatial distances. If decision times depend on spatial distances but not on distances in a propositional network then this is taken as evidence for the analogue nature of the mental representation.

In the priming technique on each trial two words are presented to the subject who has to decide whether these two words belong to the learned material or not (Ratcliff & McKoon, 1978; Wagener & Wender, 1985). The idea behind this technique is that activation of the first concept in memory starts a spread of activation. It then depends on the distance between the first and second concept how much the decision is facilitated.

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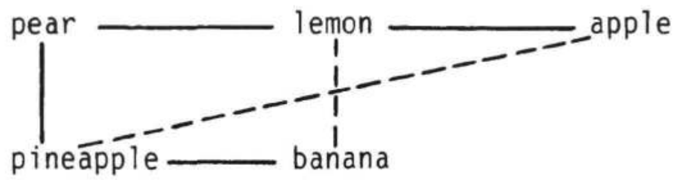

Figure 1: An example for the configurations. Solid lines correspond to sentences given to the subjects dashed lines mark relations not mentioned in the descriptions.

In the verification test a short sentence containing a spatial relation between two concepts is shown to the subject. The subject has to decide whether this sentence is true with respect to the to be remembered material or not. In linear orderings, e.g. the natural number system, a very reliable effect has been found: Decision times decrease with growing distances between concepts. This has been called the symbolic distance effect (Banks, 1977; Moyer & Dumais, 1978). Curiously, this effect seems to contradict the priming effect. Combined with the distance effect is the socalled end-anchor-effect. End anchors are the first and the last item of a finite list. If these items are combined with other items in a comparative sentence this leads to shorter decision times compared to other items with the same distance on the underlying scale.

It is the goal of this contribution to construct a model for the mental representation and processes that can explain the results from both experimental techniques. This model processes spatial information and simulates propositional as well as analogue aspects of the mental representation.

EXPERIMENT 1

Method

Subjects memorized desriptions of spatial arrangements of five common objects. Each description consisted of four sentences and was printed on a card given to the subjects. An example of one configuration is as follows.

"Fruits

The pineapple is to the left of the banana.
The pear is behind the banana.
The lemon is to the right of the pear.
The apple is to the right of the lemon."

Figure 1 shows the configuration described by these four sentences. In the experiment subjects learned eight descriptions plus two additional ones for warming up purposes. As a criterion for learning subjects were asked four questions about each configuration such as:

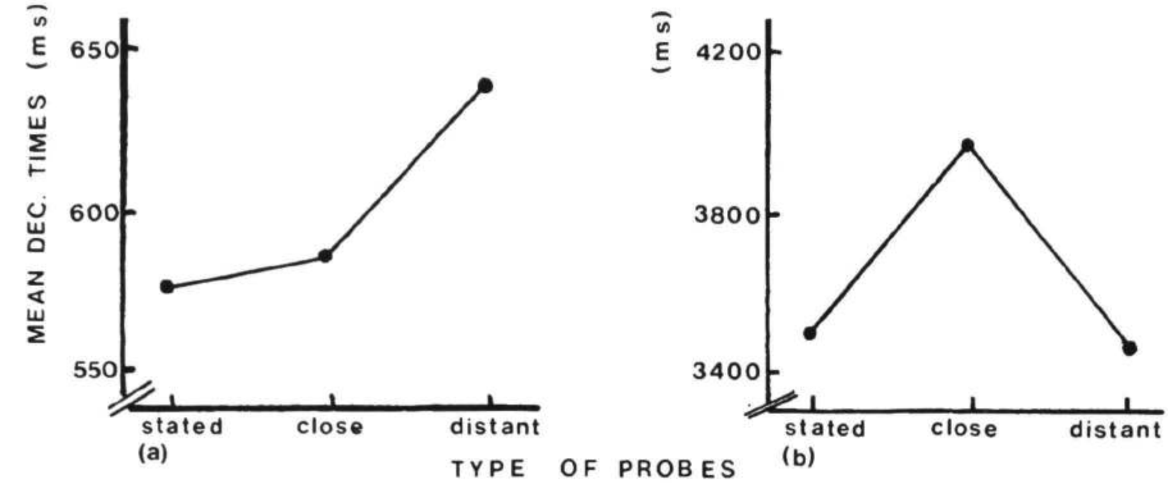

Figure 2: Mean decision times for Experiment 1 in (a) the priming task and (b) the verification task for stated, close, and distant probes.

"What is to the left of the banana?"

Learning continued until subjects could correctly answer all questions by heart.

After completing the learning task subjects participated in a priming phase. On each trial subjects were presented with the words for two objects from one configuration. The two words were shown successively on a computer screen with a 500 ms SOA. Subjects had to decide whether both objects belonged to the learned configuration or not. Decision time was measured starting with the presentation of the second word.

For each configuration two pairs of concepts were of special interest. These are called the close pair and the distant pair. In Figure 1 these pairs are marked by dashed lines. To balance possible semantic effects there were two versions for each configuration in which the objects for the close and distant pairs were interchanged.

In the verification test subjects were shown sentences of the following form:

"The pineapple is to the left of the banana."

Subjects had to decide whether this sentence was correct with respect to the given configuration or not. Again decision time was measured.

RESULTS

Figure 2 gives the results for different probes. Stated pairs correspond to sentences that were given in the description. An example from Figure 1 would be "lemon - pear". Close pairs contain words that originally did not appear in one sentence but are close together in the spatial configuration like "lemon - banana" in Figure 1. Note that distant pairs are differently constructed in

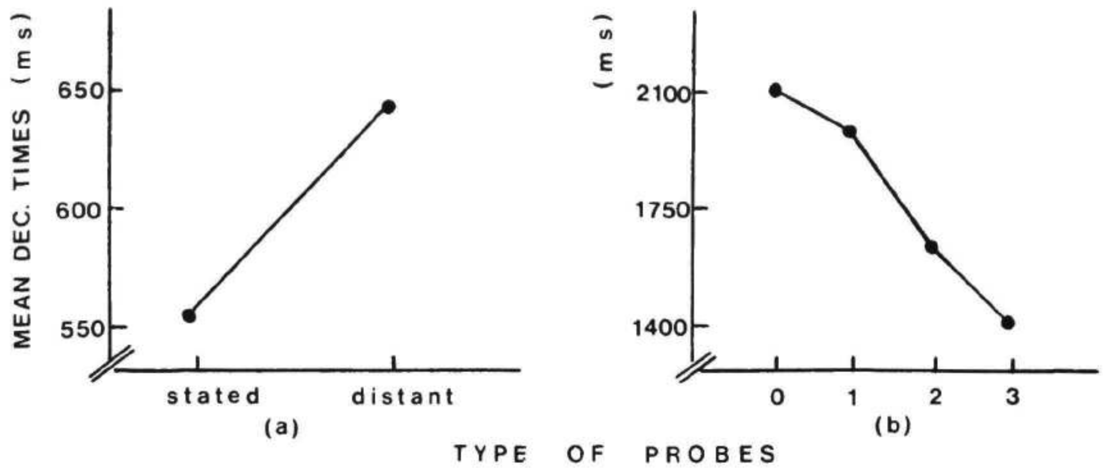

Figure 3: Mean decision times for Experiment 2 in (a) the priming task for close and distant probes and (b) the verification task for the four different distances determined by the number of objects between two test items.

the priming and verification task. In the priming task the distant pairs contain words that have the same propositional distance as the close pairs but a larger spatial distance. In Figure 1 this would be "pineapple - apple". For the verification task a distant probe would be "pear - apple". Again, these words had not appeared in one sentence. Hence, a proposition about their relationship may be called an inference. For the priming data there is an increase in reaction time from close pairs to distant pairs ($F1(1,22)=7.2$, $p < .02$; $F2(1,14)=5.51$, $p < .05$), whereas stated and close pairs are almost equal. We observed an opposite effect for the verification data: a clear decrease in reaction times from close probes to distant and stated probes ($F1(2,89)=4,53$, $p < .02$; $F2(2,21)=5.02$, $p < .05$).

EXPERIMENT 2

To investigate the processes involved in the priming and verification task in more detail we conducted a second experiment. The two dimensional configurations were reduced to one dimension.

Method

Subjects learned lists of five words each that were given to them printed on cards such as

"Fruits
pear pineapple lemon banana apple."

Each list was learned until subjects, after a short distractor task, could reproduce the complete list. The following priming task was identical to that in Experiment 1. The verification test was somewhat different from Experiment 1. Instead of a complete sentence subjects were shown two words on a screen printed on the same line. Subjects had to judge whether the words had appeared in the list in the same order. Different probes were constructed in such a way that the words had been 0, 1, 2 or 3 items apart in the original list.

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(MEMBER-OF-LIST   A)        (NEIGHBOR A B)
 POSITION: 1.1               ACTIVATION: 0

(MEMBER-OF-LIST   B)        (NEIGHBOR B C)
 POSITION: 0.6               ACTIVATION: 0

(MEMBER-OF-LIST   C)        (NEIGHBOR C D)
 POSITION: 0.1               ACTIVATION: 0

(MEMBER-OF-LIST   D)        (NEIGHBOR D E)
 POSITION: -0.4              ACTIVATION: 0

(MEMBER-OF-LIST   E)
 POSITION: -0.9
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Figure 4: Contents of long-term memory after the encoding step

RESULTS

Mean decision times are shown in Figure 3. For the priming data times are longer for distant pairs (min $F'(1,30)=4,18$, $p < .05$) pairs whereas there is an inverse relationship for the verification data: Decision times are shorter for distant compared to adjacent probes (min $F'(3,94)=10,81$, $p < .001$).

DISCUSSION

The results from Experiment 2 suggest a rather straightforward interpretation. The priming data may be explained by a spread of activation starting from the first concept and reaching the second concept earlier in an adjacent pair than in a distant pair. The results of the verification test show a clear symbolic distance effect possibly combined with an end-anchor effect. Several models have been proposed for its explanation; but none of them combines priming and verification data. The model we propose makes use of the PRISM architecture by Langley (Langley, 1983). The model consists of one working memory, one long-term memory and three production memories.

The long-term memory stores the simulation of the mental representation. The working memory contains goals, test items, and items activated from long-term memory. The first production memory includes productions that input information to long-term memory and productions that control the work of the other two production memories. The second production memory holds the productions for the priming task. The productions used in the verification task are included in the third production memory.

Figure 4 shows the content of the long-term memory after a list of five items, A B C D E, has been learned. These elements are linked via common symbols. Our model simulates the priming task by using the propagation process furnished by PRISM. The activation starts from the first element in the probe and successively activates neighboring elements. If the activation of an element reaches a threshold this element is transferred to the working memory and matched against the probe item.

The verification task has a different goal structure and needs a more complex and strategic process. An effective and short representation for this task is a list of elements where the ordering is represented by an attribute, as shown in Figure 4. We assume that the spreading activation is not relevant for this strategic process. Hence, the verification process needs only the "(MEMBER-OF-LIST Y)" elements. This representation corresponds to the model of semantic coding by Banks (1977). Because we assume an asymetrical end-anchor effect the first anchor has a higher priority than the last one. This has to be confirmed by further experiments. Furthermore, this simple model has to be modified and tested for data from the two dimensional configurations in Experiment 1.

Following the semantic code model we explain the symbolic distance effect by four steps of processing: first the encoding step, second the discrimination process, third the matching process and finally the decision by the subject. We assume that subjects have finished the encoding step before they start the task, since they have had time enough to remember the list and they were trained with two probe lists.

The crucial step is the discrimination process which utilizes the difference between the attribute values to discriminate between objects. If this difference is high, as for items A and E, this pair reaches a given threshold in fewer cycles than, for instance, items C and D.

The results from Experiment 1 pose an additional problem for the model. The not-stated close pairs lead to a fast decision in the priming but, compared to the stated pairs, to a slow decision in the verification task.

The priming data are simulated by including an additional element into long-term memory. For the configuration in Figure 1 this would be the element "(NEIGHBOR lemon banana)". For the verification data we assume that the attributes representing the spatial position have different values for the two dimensions of the configuration. Our model is not yet complete. It is conceivable that we will have to add elements to long-term memory representing surface information from the original sentences.

REFERENCES

Banks, W.P. (1977). Encoding and processing of symbolic information in comparative judgements. In G.H. Bower (Ed.), The Psychology of Learning and Motivation (Vol. 11, pp. 101-159). New York: Academic Press.

Langley, P. (1983). Exploring the space of cognitive architectures. Behavior Research Methods & Instrumentation, 15, 289-299.

Moyer, R.S., & Dumais, S.T. (1978). Mental comparison. In G.H. Bower (Ed.), The Psychology of Learning and Motivation (Vol. 12, pp. 117-155). New York: Academic Press.

Ratcliff, R., & McKoon, G. (1978). Priming in item recognition: Evidence for the propositional structure of sentences. Journal of Verbal Learning and Verbal Behavior, 17, 403-417.

Wagener, M., & Wender, K.F. (1985). Spatial representations and inference processes in memory for text. In G. Rickheit & H. Strohner (Eds.), Inferences in Text Processing (pp. 115-136). Amsterdam: North-Holland.

Wender, K.F., & Wagener, M. (1985). Spatial inferences and discourse comprehension. Proceedings of the Seventh Annual Conference of the Cognitive Science Society, 376-384.