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A CENTRAL PROBLEM IN REPRESENTING HUMAN KNOWLEDGE IN ARTIFICIAL SYSTEMS: THE TRANSFORMATION OF INTRINSIC INTO EXTRINSIC REPRESENTATIONS

Gerhard Dirlich*, Christian Freksa*, Ulrich Furbach£

* Max-Planck-Institut für Psychiatrie, Munich, West Germany

£ Hochschule der Bundeswehr, Neubiberg, West Germany

ABSTRACT

The process of representing human knowledge in artificial symbol systems contains in many cases the transformation of analog representations into propositional representations as a subprocess. We look at this transformation from the perspective of representation theory. We discern intrinsic and extrinsic representations. Intrinsic representations are based on media which are structurally similar to the world of represented objects, while extrinsic representations are based on highly general but structurally poor media and require explicit descriptions of all relevant structural aspects of the represented object.

A prominent aspect of transformations of analog representations into propositional ones is that extrinsic representations have to be generated from intrinsic ones. Such processes seem to be not well understood, so far. We believe that this is a fundamental reason for some of the difficulties encountered in feeding artificial systems with human knowledge. We suggest to reconsider this transformation problem within the framework of an analog - propositional dualism in representation.

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THREE PROBLEM SOLVING SITUATIONS

A well-known non-verbal intelligence test is the Standard Progressive Matrices, SPM (RAVEN 1958). In each test problem, the subject has to find the element in the solution set which completes the test pattern in a globally consistent way (Fig. 1).

***** figure 1 *****

There are two versions of the SPM. One version allows physical manipulation of the solution set, i.e., paper cards can be physically inserted into a slot in the test pattern (situation A). In the other version, test pattern and solution set are printed on the same page of a booklet, so that the subject can visually inspect test pattern and solution set (situation B).

Let us consider an hypothetical situation where an artificial problem solving system plays the puzzle (situation C).

In all three situations the problem is given in the physical world. In situation A, the problem can be solved by physical manipulation of the object. The subject has solved the problem as soon as he has obtained a "good figure" (c.f. ANDERSON 1980, pp. 53-54). Note that the subject does not need a representation of the problem as such in his mind. In contrast, situation B requires some mental representation of the problem. By applying cognitive procedures, the physical problem solving process can be mentally simulated. Then, the mental solution triggers an appropriate action in the physical problem world. In situation C, the problem must be represented in the domain of the artificial system.

In the present paper we will discuss the general structure of situation C in the light of cognitive representation theory (PALMER 1978). We believe that this can clarify some aspects of the representation of human knowledge in artificial systems. We suggest issues in knowledge representation which require further study for a better understanding of intelligent behavior.

MEDIA OF REPRESENTATION

A close-up look at the structure of the problem solving procedures in situations A, B, and C reveals some important differences (Fig. 2).

***** figure 2 *****

They differ with respect to the structure of the problem solving procedure, especially with the types of representation involved. The problem solving procedure in situation C can be broken up into a sequence of subtasks: 1. the creation of a symbolic representation of the physical problem (c in Fig. 2C), and 2. its transformation into a computational representation (d in Fig. 2C). In case a symbolic representation of the problem is generated outside the symbol processing system (solid box in Fig. 2C), the task of the system is a classical symbol processing task. The preceding generation of the symbolic representation of the real-world problem must still be done by a human.

Is it possible to move the interface of the system in between real-world problem and its symbolic representation? In other words: is it possible to create symbolic representations of real-world problems automatically? In the following, we will discuss this question from the perspective of representation theory.

TRANSFORMATION OF INTRINSIC INTO EXTRINSIC REPRESENTATIONS

Representation theory appears to be a powerful tool for a more detailed study of the generation of symbolic representations of problems in the real world. Following Palmer (1978), a representation system mainly consists of two related but functionally separate worlds. In order to specify a representation system, five aspects have to be defined:

1. what the represented world is,
2. what the representing world is,
3. what aspects of the represented world are being modeled,
4. what aspects of the representing world are doing the modelling,
5. what the correspondences between the two worlds are.

The two worlds in such a representation system consist of objects that are characterized by the relations among them. The correspondence between the represented world and the representing world must preserve at least some of these relations. Two fundamentally different forms of representation should be distinguished: intrinsic and extrinsic ones. A representation is called intrinsic whenever a representing relation has the same inherent constraints as its represented relation; it is called extrinsic whenever the inherent structure of a representing relation is arbitrary and that of the represented relation is not.

Let us assume here that the creation of a symbolic representation is a two-step process: in the first step, an analog, "natural isomorphism" - type representation (SHEPARD 1975) is created. In a second step, the analog representation is transformed into a symbolic representation. A symbolic representation is a propositional representation which is sufficiently complete for solving the problem.

Palmer (1978) has argued that analog representations are intrinsic, whereas propositional representations are extrinsic. Thus, the just stated assumption allows for an interesting conclusion: the transformation of the analog representation into a propositional representation requires the generation of an extrinsic representation from an intrinsic one; this process is a crucial step in generating a symbolic representation.

The entire problem solving process is now segmented into three major subtasks. One subtask is the transformation of an analog representation into a propositional, i.e. symbolic, representation. We have just clarified that this process transforms an intrinsic representation into an extrinsic one. The other two subtasks, the generation of the initial analog representation (cf. MARR 1976) and the symbolic problem solving procedure (cf. SIMON 1978) are relatively well understood.

ANALOG - PROPOSITIONAL DUALISM

Analog and propositional representations are regarded as the two major candidates of representations in human memory. We will briefly point out some of the impacts of the so-called analog - propositional controversy in psychology (PYLYSHYN 1973, KOSSLYN 1976) on artificial intelligence. Speculations about the nature of representations in human memory according to which they are either analog or propositional can be traced back to pre-scientific times. Until today, psychologists have come up with empirical support for either type of representation. The state of the art is probably best described as a growing belief that "analog" and "propositional" describe differing appearances of a unique underlying form of representation.

It might be appropriate to view our present understanding of representation in memory not as a controversy but rather as an analog - propositional dualism much like the wave - particle dualism of light in physics.

If we assume this point of view, some questions are shifted into the focus of interest which have not been dealt with extensively, so far: 1. what are the conditions under which knowledge appears in analog or propositional form, respectively? this is a question aiming at cognitive psychologists; 2. how can transformations between one form and the other be described formally? this is a question aimed at AI. There have been attempts to develop partial ad-hoc solutions within special domains (e.g. WINSTON 1975). However, to the knowledge of the authors, there have been no sufficiently general approaches on the level of representation theory.

CONCLUSION

Let us return to the picture puzzle depicted in figure 1. What would a propositional representation of this problem look like? Clearly, many symbolic representations are possible. We outline one of them:

> The test pattern consists of 9 fields. The position of each field can be propositionally described by its row (x) and its column (y).
>
> The position of the black square relative to its field can be described with respect to three rows (x') and three columns (y').
>
> Obviously, the proposition (x' = x) & (y' = y) holds for the 8 complete fields of the test pattern.
>
> Thus, one must conclude that it should also hold for the missing field. Therefore, pattern 5 in the solution set is correct.

The idea behind this representation can be summarized as follows: the position of the black square relative to its field is the same as the position of the field relative to the entire test pattern. Obviously, the propositional representation does not immediately pop out of the picture. On the contrary, once the solution of the puzzle is found it appears as an artificial, not easily graspable post-hoc justification of the decision.

In other words, it may require more mental effort and more intelligence to translate the problem into a representation which is appropriate for our present symbol-based problem-solving procedures than to solve the problem in other ways. Two alternative approaches are conceivable: 1. to design intelligent devices which can directly operate on analog representations, or 2. to explore the problem of transforming intrinsic into extrinsic representations and to develop algorithms which can perform such transformations.

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C7

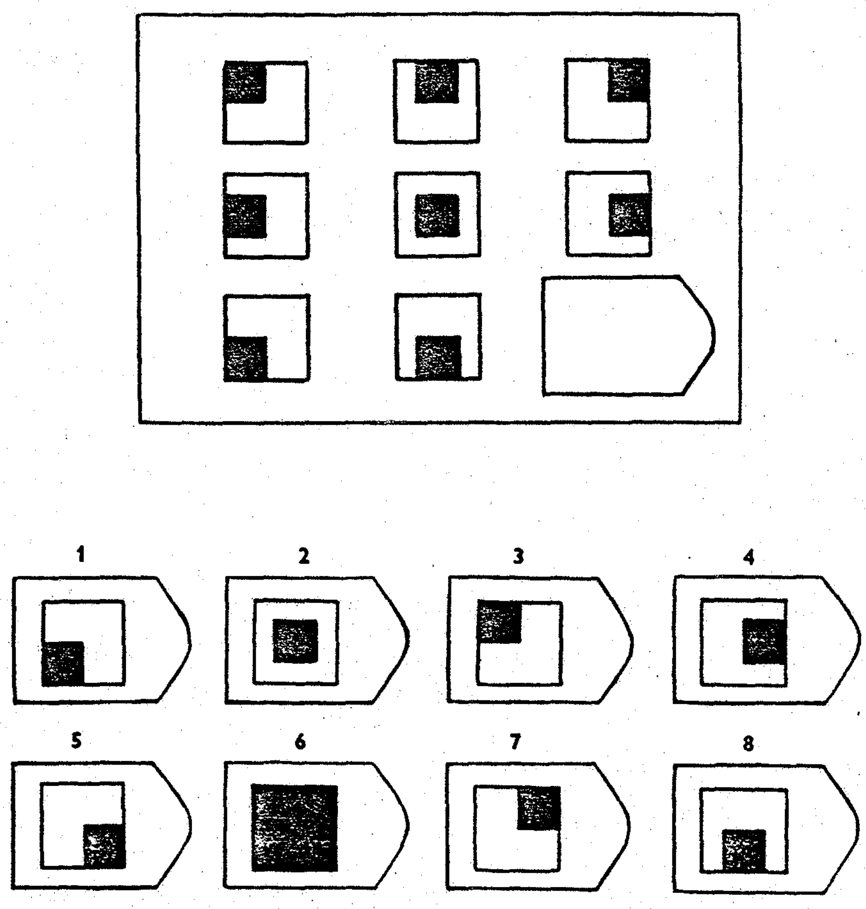

Fig. 1. Problem C7 from the Standard Progressive Matrices intelligence test. Upper part: test pattern, missing field at lower right corner. Lower part: multiple choice solution set.

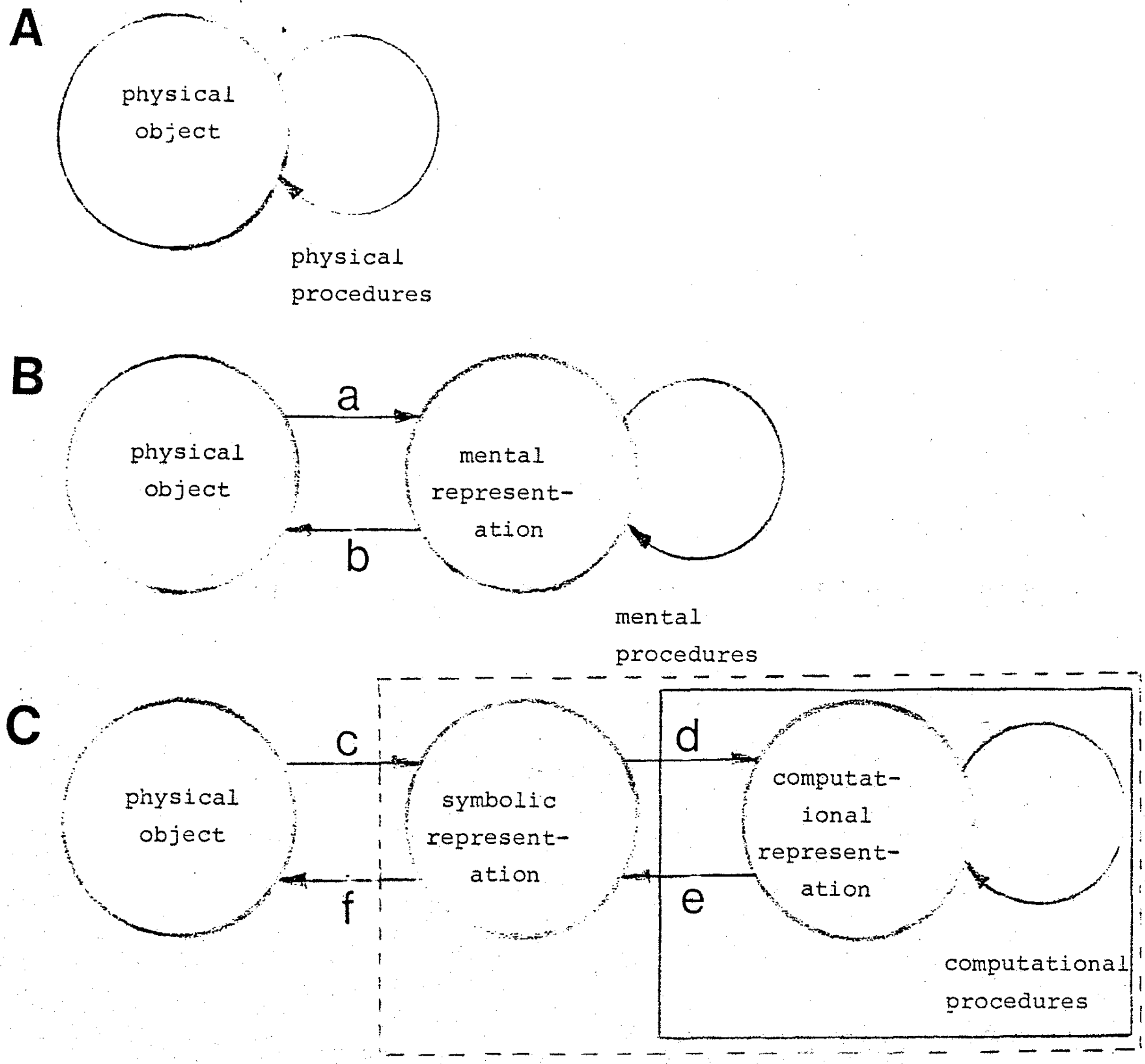

Fig. 2. Three problem solving situations. The problem is given in the physical world. In situation A it is solved by physical procedures. In situation B the problem and its solution is mentally simulated. In situation C, a symbolic representation of the problem is generated which then is fed into an artificial problem solving system.