

The Spatial Nature of Mental Models

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1 The Basic Idea of Mental Models

The idea that mental representations are “small-scaled models of external reality” can be traced back to Craik (1943). This means, that a mental representation shares its structure with what it represents. Therefore, it is possible to model reality in thoughts and to learn about it without affecting it. It enables us to reason, to know what will or would be the case if this and that were to happen. Johnson-Laird (1983) developed a theory of mental models that can explain a wide variety of phenomena in reasoning. The power of mental models is grounded in the way the world is represented. It is not the logical structure (such as in propositions) or some artificial constructions (such as circles standing for sets) that are represented, but rather single objects taking part in a situation and the relations among them. Of course, this very basic idea must be extended, for sets must be representable as such, for example. However, the advantage of this account is that the world is represented in a simple and natural way. Johnson-Laird shows that reasoning with mental models leads to logically valid conclusions when no limit of capacity is assumed.

2 The Philosophical Account

The intuitive idea that mental representations are similar to what they represent goes back to Greek philosophers. However, the notion of similarity is very vague, and several specifications have been proposed (cf. Cummins 1989). The most promising account to be applied to mental models is the isomorphism theory introduced by Cummins (1996). He proposes that the relation between a representation and the represented is isomorphism. This leads to the assumption that representation “lies around everywhere”, which is certainly too strong. Still, isomorphism can be viewed as a necessary condition for representation. Moreover, a lot of representations do not have as many parts as the represented and do not exhibit all relations. Hence,

isomorphism must be assumed to be eventually partial in the sense that it does not share the whole structure with its represented. Nevertheless, I will use the notion of isomorphism to explain and sharpen the notion of ‘shared structure’ used by Johnson-Laird.

In mathematics, structures are sets over which one or more functions and/or relations are defined. Two structures \mathfrak{A} and \mathfrak{B} are said to be isomorphic if there is a bijective mapping I between the $a_i \in \mathfrak{A}$ and the $b_i \in \mathfrak{B}$, such that for each function f : $I \langle f^{\mathfrak{A}}(a_n, a_m, \dots) \rangle = f^{\mathfrak{B}}(b_n, b_m, \dots)$ and for every relation R : $I \langle R^{\mathfrak{A}}(a_n, a_m, \dots) \rangle = R^{\mathfrak{B}}(b_n, b_m, \dots)$ ¹. Thus, if X is a representation of Y , then for every element of Y there must be exactly one element of X corresponding to it. Johnson-Laird meets this requirement, for the basic idea of mental models is to represent each individual taking part in a situation. The appropriate model for the sentence “The apple is left of the banana” hence involves two tokens, one for the apple and one for the banana.

As already mentioned, the mathematical notion of isomorphism is too strong a requirement for most representations. It is obvious, that, for example, the architect’s model of a house does not have as many elements as the real house. It contains elements representing walls and windows, but it will seldom contain elements representing single bricks. Similarly, there are many relations holding between the apple and the banana in the real situation (e.g. concerning their color or size) which are very unlikely to be contained in the example model. It is thus useful to introduce the notion ‘relevant part of a structure’, which is determined by the usage of the representation. If I want to reason about the spatial relation of fruits, a mental model containing spatial relations will suffice. On the other hand, if I want to decide which fruit to eat, there will be certainly more relevant relations to represent (e.g. is sweeter than).

Isomorphism is a relation between structures. Hence, a model is itself a structure, i.e. a set over which functions and relations are defined. Thus, the appropriate model in the example can be written as

$$\langle \{a, b\}, leftof = \{\{a, b\}\}, rightof = \{\{b, a\}\} \rangle.$$

The crucial point is that a model does not represent the relations involved as symbols (or labels); it contains itself relations which hold between its elements regardless of whether it is used as a model or not. Because the relations have the same logical features as the relations of the real situation (see the definition of isomorphism), they exhibit the same structure. This is why the isomorphism theory is so attractive: it explains straightforwardly

¹cf. Ebbinghaus, Flum & Thomas (1992, p. 49)

why our conclusions are correct (given that we have a good model and no capacity limitations).

3 The Structure of Mental Models

Johnson-Laird believes mental models to contain symbols for relations, for example arrows to represent family relationship. This works, however, only if the relation ‘being connected by an arrow to’ has the same logical features as ‘being related to’. In spatial reasoning the relations may be the same (‘left to’, ‘right to’), but in other fields this is hardly to be the case. Two mental tokens simply do not stand in the relation of family relationship. Hence, to represent family relationship in a mental model a relation must be found that has the same logical features; if there is only a symbol which does not share the logical features, the transferability of information to the represented cannot be assured.

Since mental models are natural representations² the relations contained in them are to be assumed natural as well. The point here is that mental models do not involve sophisticated mathematical or other abstract notions. Therefore, the problem of how children acquire logical reasoning can be — according to Johnson-Laird — explained. All we need to assume children to possess is a working apparatus of perception³. The mental pictures of perception thus are the basis from which mental models can be extracted by abstraction. The relations contained in mental models are therefore all relations that we can find in perception as well. Hence, the categories of perception are the categories of mental models. Since the most important category of our perception seems to be the space (it is a dimension of the visual, auditive, haptic sense and the sense of balance), at least most mental models will be spatial in nature, regardless of the field of reasoning. The only models to be excluded from this conclusion will be very basic models representing very basic concepts such as ‘sweeter than’ or ‘lighter than’. The more complex models used in reasoning are, on the contrary, the more likely they contain spatial relations (since the space is a very basic category of perception). Indeed, we seem to apply spatial models with great ease (externalized mental models, e.g. sketches, are mostly spatial in a relevant way).

Taken together the postulation of shared structure, which is explained in terms of isomorphism, and naturalness, it must be concluded that mental models contain only perceivable relations. Symbols or labels cannot fulfill

²cf. Johnson-Laird (1983, p. 93)

³Of course there must be other abilities like memorizing, including different perception data in one model, and so on.

the theoretical requirements of mental model theory. The constraint of perceivability is necessary for the explanatory power of mental models.

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