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The representation of objects and location in conceptual networks

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Background

The primary concepts on which our spatial knowledge is based must have its origin in early individual development. One of these concepts is the notion of an object. Characteristic of the development of this concept is the so-called A-not-B-error (Piaget 1937). The error occurs in 6 to 8 months old infants that persist in reaching for location A, where an object was hidden several times, even though the correct location is B, where the object is actually hidden. A necessary condition for the error to occur is a short delay between the moment of hiding the object and of the child's grasping. If the child is allowed to grasp the hidden object immediately after it has been hidden, the error does not occur.

Main contribution

In order to explain cognitive phenomena such as the Anot-B-error, a conceptual network will be used as a general framework for the representation of cognitive processes on the basis of principles of self-organization. To introduce the framework first some general issues will be discussed, before we will turn to the more specific topic of the A-not-B-error.

In an efficient representation of the world the locations and identity of objects must be represented separately. Therefore one of the central components of a conceptual network is a spatial map in which the spatial relationships of the objects in the world are represented: the relationships between the excitation patterns in the

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Groningen, The Netherlands e-mail: p.h.de.vries@rug.nl map are assumed to be isomorphic to those among the objects. The identities of objects are represented separately from the spatial map. The memory traces of these objects are represented at the neural level as cellassemblies. These clusters of neurons are a consequence of the principle proposed by Tanzi (1893) and Hebb (1949) that simultaneous activity in a pair of neurons strengthens or creates a connection between them.

An implication of the notion of cell-assemblies, is that they must have a critical threshold (Dalenoort 1985) above which the excitation level will grow autonomously to its maximum level. If the excitation level of a cellassembly is above the critical threshold, the corresponding memory trace is said to be in short-termmemory. Below the critical threshold a memory trace is in a state of priming, and we are not conscious of it.

Within a conceptual network the nodes represent cellassemblies and the connections represent excitation loops between them. Neurons are not exclusive to one cell-assembly only. Depending on the overall activation pattern in the network, a neuron may participate in different cell-assemblies.

In order to explain the mechanism for binding in a conceptual network, we will discuss a simple task in which this phenomenon occurs:we can directly associate two arbitrary words. How is it possible that the two corresponding excitation patterns start to resonate? It is not sufficient that the two excitation patterns occur simultaneously since in the brain many excitation patterns are simultaneously active. A solution may be that the two items belong to the same context (Dalenoort and De Vries 1998; De Vries 2004a).

At the neural level this context corresponds to a subnetwork from which the memory traces of both items are activated. This activation makes the pair to be coupled specific. Neurally there is a specific resonance at the level of the spikes, produced by both cell-assemblies,



due to the participation in the same context. The notion of spike resonance is compatible with the phenomenon of 'binding by synchrony', reported in the neurophysiological literature (Roelfsema et al. 1997). Because of the proposed mechanism for binding conceptual networks are biologically plausible models for learning and development. When the resonance carrying a temporary connection exists long enough, the conditions for the Tanzi-Hebb rule apply. New synapses may be formed or existing ones are strengthened. Temporary connections may thus lead to the formation of new cell-assemblies.

In order to explain the A-not-B-error in terms of a conceptual network (De Vries 2004b), two conditions play a crucial role: the existence of a task network and the process of consolidation of excitation loops. A task network represents the procedural knowledge necessary for carrying out a task. It contains memory traces that will be temporarily bound to the actual objects on which the task is performed. For the A-not-B-task these memory traces represent the identity of the object to be grasped and its location.

The mechanism responsible for the consolidation of excitation loops is based on the phenomenon of residual activation. In Fig. 1 this process is illustrated: the three peaks in the curve for Location A (the evolution of the excitation level of the excitation pattern representing Location A in the spatial map) correspond to number of times the toy was hidden at location A.



Fig. 1 Consolidation of excitation loops in the simulation of the Anot-B task

Each of these peaks indicates a period of autonomous growth, followed by a decay. The successive reactivation leads to consolidation in the excitation pattern for Location A, since each new period of autonomous growth builds on the residual excitation of the previous one. When the toy is finally hidden at location B, the corresponding excitation curve also shows a period of autonomous growth and exceeds the excitation level of the curve for location A. However, when the curve for location B starts to decay, it sinks beneath the one for Location A, since it is not yet consolidated.

We then see an element of competition in the binding process in a conceptual network: when a node has several candidates for binding, the one with the highest activation level wins. From a cognitive viewpoint this binding constitutes an error if there is a delay between hide and grasp. Only in that case will the excitation curve of the erroneous Location A be higher than the one for the correct Location B. Accordingly the wrong excitation pattern in the spatial map will be bound to the task network necessary for the grasp action. This explains the role of the discussed delay in the A-not-B task.

Some researchers of individual development (Thelen et al. 2001) reject the notion of 'object concept'. In their opinion the notion lacks the 'fluidity and context-dependentness' that is necessary in order to account for these phenomena. One of the claims of this paper is that an object concept represented as a cell-assembly participating in the binding processes in a conceptual network, does not suffer from these short-comings.

The development of new cell-assemblies on the basis of the Tanzi-Hebb-rule makes it possible that new bindings occur, i.e. bindings between sub-networks that before the development did not exist. Because of these bindings new behaviour is possible that can be realized 'all-at-once'. This corresponds to a 'jump' in development that is characteristic of the succession of Piagetian developmental stages. The gradual development within a stage corresponds to the gradual changes accounted for by the Tanzi-Hebb-rule, which operates on a larger timescale than the mechanism for binding. Those temporary connections that persist, will give the Tanzi-Hebbmechanism the time to do its work. We thus can discover the interplay between binding and the formation of new synapses in the stages of cognitive development. Since connectionist networks (O'Reilly and Munakata 2000) do not have a mechanism of dynamic binding these developmental jumps are difficult to explain in these models.

Implications

The binding processes can be generalized to identify of possible causes two complementary neuropsychological syndromes: one in which patients can describe the semantics of an object in language, but fail to manipulate the object in the proper manner (Forde and Humphreys 2000), and the other in which they do use the object itself properly, but are unable to formulate its meaning (Milner and Goodale 2002). In the former the memory trace of a perceived object reaches the critical threshold but the binding processes in the network are disturbed. Therefore the temporary resonance between memory trace of the object, the excitation pattern in the spatial map representing its location, and the task network-necessary for the grasp action-will not occur. So a subject is conscious of the object and the location involved in an action, but the procedural knowledge of the task cannot be bound to the actual object perceived in the visual field. In the second syndrome disturbance of the network leads to a subthreshold excitation level in the memory traces



involved. Nonetheless the established, weaker binding between the memory trace of the object, its location in the spatial map and the task network leads to a grasp action. Since the activation level in the memory traces involved does not pass the critical threshold, they will not produce a conscious experience and will not lead to a verbal report.

The proposed model sheds some new light on distinctions made in cognitive psychology between the 'where' and the 'what'-system. Recently it has been argued that this distinction should be reformulated as that between a 'what' and a '(where-and-)how' system. However, this reformulation becomes problematic if no account of binding processes is given. Within a conceptual network both distinctions can be accommodated.

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