How Anchors Allow Reusing Categories in Neural Composition of Sentences

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Abstract: van der Velde's & de Kamps's neural blackboard architecture is similar to "activation trace diagrams" (Clancey 1999), which represent how categories are temporally related as neural activations in parallel-hierarchical compositions. Examination of other comprehension examples suggests that a given syntactic categorization (structure assembly) can be incorporated in different ways within an open composition by *different kinds of anchoring relations* (delay assemblies). Anchors are categorizations, too, so they cannot be reused until their containing construction is completed (bindings are resolved).

Conceptual Coordination (Clancey 1999, hereafter CC) attempted to bridge connectionism and symbolic theories of cognition by analyzing slips, autism (Clancey

2003), learning in well-known architectures (e.g., MOPS, EPAM, SOAR), dream phenomenology (Clancey 2000), and natural-language comprehension difficulties. The neural blackboard architecture of van der Velde & de Kamps (vdV&dK) (pp. 15ff) has properties that directly map to “activation trace diagrams” (CC, p. 6), including: (1) representing a conceptualization of a sentence on a blackboard; (2) not copying structures (i.e., one physical instantiation in a given sentence diagram); (3) preserving temporal relations of neural activation; (4) composing word assemblies by structural relations (e.g., a noun phrase, NP); (5) creating word structures (e.g., “the cat - NP”) by temporary binding/tagging (CC, p. 273); (6) binding words to multiple structures in different roles (e.g., both agent and theme); and (7) holding a partially completed structure active (a “delay” activity in vdV&dK; “anchor” in CC, p. 246).

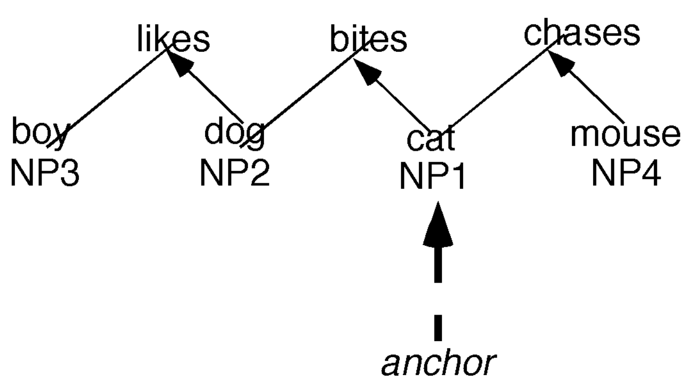

Figure 1. Activation trace diagram of "The cat that the dog that the boy likes bites chases the mouse" (vdV&dK p. 14; compare to CC, Fig. 17, p. 46)

Figure 1 represents conceptualization of a double-centered embedded sentence from vdV&dK using the notation from CC. During the composition process, the first noun phrase (NP1) is held active by an anchor, contained within subsequent phrases, and then resolved in an agent role by a right branch. A verb phrase is represented (in vdV&dK's terms) as an agent and verb on a line segment (e.g., "boy-likes"), with a theme (e.g., object, "dog") indicated by an arrow below. This sentence is analogous to "The cat that the bird that the mouse chased scared ran away" (CC, fig. 10.14, p. 256). vdV&dK (pp. 47ff) indicate that these sentences are difficult to comprehend because there are two NPs (NP2 and NP3) that could bind to two different theme assemblies (e.g., "likes" and "bites").

Based on analysis of other convoluted examples (provided by Lewis 1996), the binding problems involved in sentence comprehension can be restated and generalized. The following principles postulate restrictions on how word (semantic) and structural (syntactic) categorizations are employed in a given construction (from CC, pp. 261–62):

(P1) A semantic categorization can play multiple syntactic roles but not the same role twice in an active construction (e.g., "cat" cannot be an agent in two verb phrases).

(P2) A syntactic categorization may "index" multiple semantic categorizations but may be active only once at a given time (e.g., only one active NP; the others are in "completed" verb phrases).

(P3) The use of an anchor allows a syntactic categorization to be "open" as *the head of a sequence* twice at a given time (e.g., in Fig. 1 the anchor holds the NP at the head, allowing subsequent NP categorization activations). The anchor is itself a categorization relating syntactic categories (i.e., this anchor represents the relation “agent-NP”); the neural processes representing the syntactic categorization NP are actually released.

(P4) Meaning construction (comprehension) is a sequential behavior, not holding a parse tree or “moving” items in a data structure.

(P5) Two general kinds of anchors are possible, one holding an embedded sentence and another holding a relative pronoun or NP within a relative phrase (see example below). Anchors serve as “stacks” that allow one level of recursion, in the computational sense that the stack may be “popped” and compositional processing returns to the previously anchored element. A higher-order construction must be closed off before returning to an anchor categorization.

(P6) Multiple anchors may appear in one utterance, but each must categorize a different syntactic relation (e.g., embedded proposition, relative pronoun object, noun object, noun subject).

(P7) Multiple conceptual dimensions are operating simultaneously, including different kinds of NP categorizations, and conceptual organizers also include rhythm, stress, and visualization. These dimensions allow and facilitate reactivation and composition of multiple object and event references during the comprehension construction process (consistent with vdV&dK’s relation of visual and verbal processing, sec. 8, para 1).

These principles imply a refinement of vdV&dK's neural architecture. In particular, vdV&dK say that a set of structure assemblies, whose number relates to memory span (sec. 6.7, para 1), can be simultaneously active. My analysis suggests that these are not multiple activations of a given structure assembly but categorizations of different relations constituting *different kinds of anchors* (delay assemblies connecting structure assemblies). For example, illustrating P5, the sentence in Figure 2 is impossible to comprehend because the opening ambiguous role of Fred (subject or indirect object?) requires two agent-NP anchors (for Fred and "the woman") to be active. Other examples suggest that the anchors shown for NP2 and NP3 are different syntactic relations so they are allowed (Principle 6)—anchor1 is "relative pronoun-NP," and anchor2 is agent-NP. Accordingly, we can comprehend "The woman whom the man who hired me married is tall." But the sentence in Figure 1 is confusing because it requires the agent-NP anchor to be active in different ways at the same time (for "the boy" and "the dog").

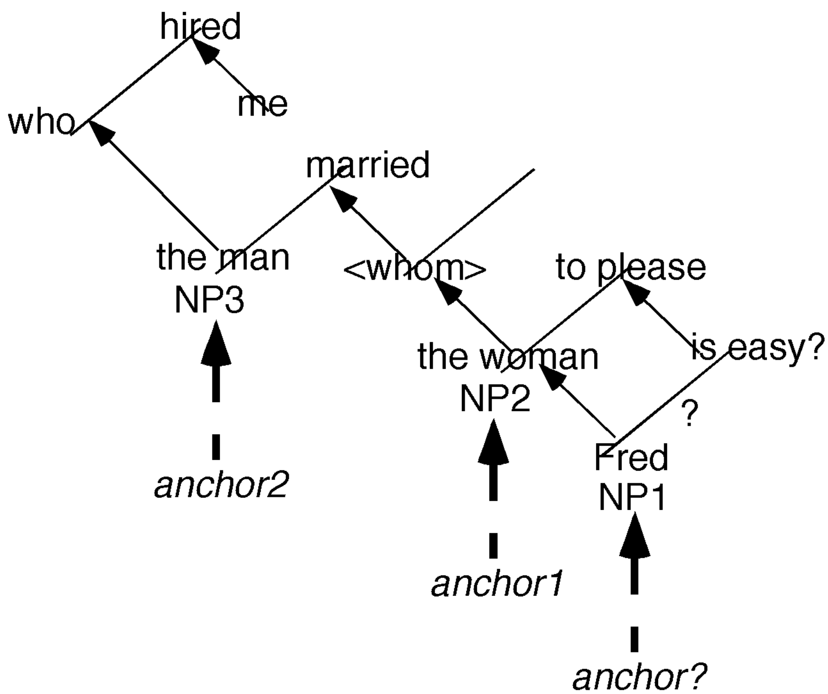

Figure 2. Activation trace diagram of "Fred is easy for the woman whom the man who hired me married to please" (example from Lewis [1996]; see CC, Fig. 10.18, p. 264).

I believe the restriction on anchors follows naturally from vdV&dK's architecture (sec. 6.7, para 1). The generalization I propose is that any kind of "assembly" (categorization) can be active only once until, in the temporal process of comprehension, the binding relations are resolved in its contained categorization (e.g., a VP), allowing the constituent categorizations to be freed for reuse. Hence, just as a word can play a role (e.g., agent) in only one way in a sentence, an anchor (a delay connecting a structure assembly) is a categorization, too, and it can be active (incorporated in an open construction) in only one way at a time. All this amounts to the rule: "no copying."

vdV&dK provide a neural model that supports and refines the postulates of CC. But the CC analysis provides many more examples that can be used to refine a theory of neural mechanisms. The process of combining structures on a "neural blackboard" can be mapped to problems of autistics in conceiving agent relations (Clancey 2003) as well as categorizing and sequencing discoordinations in verbal slips (CC, fig. 6.7, p. 161). Indeed, our dream of relating neural and "symbolic" analyses of cognition is progressing nicely.

References

Clancey, W. J. (1999) *Conceptual coordination: How the mind orders experience in time.* Lawrence Erlbaum.

Clancey, W. J. (2000) Conceptual coordination bridges information processing and neuropsychology. *Behavioral and Brain Sciences* 23(6): 919–22.

Clancey, W. J. (2003) The Newell Test should commit to diagnosing dysfunctions. *Behavioral and Brain Sciences* 26(5): 604–605. commentary on Anderson, J. R. and Lebiere, C. The Newell test for a theory of cognition. *Behavioral and Brain Sciences* 26(5):587-601.

Lewis, R. L. (1996) Inference in short-term memory: The magical number two (or three) in sentence processing. *Journal of Psycholinguistic Research* 25: 93–115.