Commentary on **William J. M. Levelt, Ardi Roelofs, & Antje S. Meyer (1999). A theory of lexical access in speech production. BBS 22(1):1–75.**

Abstract of the original article: Preparing words in speech production is normally a fast and accurate process. We generate them two or three per second in fluent conversation; and overtly naming a clear picture of an object can easily be initiated within 600 msec after picture onset. The underlying process, however, is exceedingly complex. The theory reviewed in this target article analyzes this process as staged and feedforward. After a first stage of conceptual preparation, word generation proceeds through lexical selection, morphological and phonological encoding, phonetic encoding, and articulation itself. In addition, the speaker exerts some degree of output control, by monitoring of self-produced internal and overt speech. The core of the theory, ranging from lexical selection to the initiation of phonetic encoding, is captured in a computational model, called WEAVER + +. Both the theory and the computational model have been developed in interaction with reaction time experiments, particularly in picture naming or related word production paradigms, with the aim of accounting for the real-time processing in normal word production. A comprehensive review of theory, model, and experiments is presented. The model can handle some of the main observations in the domain of speech errors (the major empirical domain for most other theories of lexical access), and the theory opens new ways of approaching the cerebral organization of speech production by way of high-temporal-resolution imaging.

Syntactic representation in the lemma stratum

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Abstract: Levelt, Roelofs, & Meyer (henceforth Levelt et al. 1999) propose a model of production incorporating a lemma stratum, which is concerned with the syntactic characteristics of lexical entries. We suggest that syntactic priming experiments provide evidence about how such syntactic information is represented, and that this evidence can be used to extend Levelt et al.'s model. Evidence from syntactic priming experiments also supports Levelt et al.'s conjecture that the lemma stratum is shared between the production and comprehension systems.

An important part of Levelt et al.'s (1999) impressively detailed model of lexical access in production is the distinction between the lemma stratum, which is concerned with syntactic information, and the form stratum, which is concerned with morpho-phonological information. Following an initial stage where appropriate lexical concepts are activated, lexical processing proceeds via the selection of a lemma and its associated syntactic characteristics. Selecting the lemma "escort," for example, leads to the retrieval of information that it is a transitive verb, and the setting of diacritical parameters for features such as tense, aspect, number, and so on. However, their model provides relatively little detail about the way in which such information is represented. In particular, Levelt et al. do not consider the representation of combinatorial information (i.e., information that specifies how a word may combine with other linguistic units to form larger structures). Clearly, accessing such combinatorial information is crucial for producing multiple word utterances, and so, for embedding their model of single word production into a more comprehensive model of language production (cf. commentaries by Ferreira [1999]; Gordon [1999]; and Roberts et al. [1999]).

In a recent series of experiments using a syntactic priming paradigm (e.g., Branigan et al. 2000; Pickering & Branigan 1998), we have explored how syntactic information might be represented in the lemma stratum. Syntactic priming is the phenomenon whereby previous processing of a sentence with a particular syntactic structure (e.g., a double object structure like "The boy gave the girl the apple") increases the likelihood of producing that structure in a subsequent utterance. Previous experiments have shown that this tendency cannot be attributed to thematic, lexical, or metrical factors (Bock 1986; 1989; Bock & Loebell 1990). We have argued that syntactic priming effects are informative about syntactic representation because they depend upon the processor recognising a syntactic relationship between two otherwise unrelated stimuli (Branigan et al. 1995; Pickering & Branigan 1999).

In Pickering and Branigan (1998), we proposed an extension to Levelt et al.'s model of the lemma stratum. As in their model, we suggested that lemma nodes representing the base (uninflected) form of a word are linked to nodes representing category information (e.g., noun, verb), and to nodes representing feature information (e.g., tense, aspect, number). Each category and each feature is encoded via a single node. Therefore, all verb lemmas connect to the same verb category node, to the same present tense node, and so on. In addition, we proposed a set of combinatorial nodes that encode combinatorial potential. For example, the lemma for a verb that can appear in a double object structure is linked to a node that licenses a double object structure. When the verb is selected during production of a sentence, one of the combinatorial nodes linked to it is also selected; this then guides construction of the appropriate syntactic structure. Thus, selection of the node associated with a double object structure licenses construction of that structure. We suggested that syntactic priming occurs because combinatorial nodes retain residual activation after being selected, and this increases the likelihood of their reselection in subsequent processing.

Our extension of Levelt et al.'s model predicts syntactic priming will occur from one form of a verb to another (e.g., from "gives" to "giving") because the combinatorial nodes are linked to featurally unspecified lemma nodes. It also predicts priming will occur from one verb to another (e.g., from "gives" to "shows") because the same combinatorial node is linked to all verbs that can appear in that structure. A series of experiments employing a sentence-completion technique tested these hypotheses (Pickering & Branigan 1998). Overall, we found reliable syntactic priming effects: Participants are more likely to produce a double object target completion after producing a double object prime completion, and similarly for prepositional object completions. As predicted, the magnitude of the effect is not affected by whether the prime and target involve the same or different versions of the same verb. This is strong evidence that the locus of syntactic information is indeed the (featurally unspecified) lemma, and not the (featurally specified) word form, as proposed by Caramazza and Miozzo (1997; cf. commentary by Harley [1999]). Priming also transfers from one verb to another, though the magnitude of the effect is smaller than when the same verb is repeated. In addition, we found that priming does not depend upon the exact repetition of terminal categories, which suggests that information is encoded by the combinatorial nodes in terms of abstract phrasal categories.

In subsequent experiments (Branigan et al. 2000), we have found that syntactic priming effects also occur in dialogue. Speakers are more likely to produce a structure if they have just heard that structure produced by another speaker. These results provide strong evidence that comprehension and production access

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shared syntactic representations, and hence that the lemma level is shared between the comprehension and production systems, as Levelt et al. hypothesized. In fact, our findings are much stronger evidence for a shared level of syntactic representation than is Levelt et al.'s own evidence, which depends upon semantic interference – by hypothesis mediated by the lemma level – from visually presented distractors during picture naming. Our results show further how it is possible to integrate the study of comprehension and production, as Cutler and Norris (1999) espoused in their commentary, within Levelt et al.'s framework.

Overall, the syntactic priming results are in keeping with our extension of Levelt et al.'s model. These results demonstrate that this type of framework can account for not only single word production, but also aspects of multiple-word utterance production. Furthermore, they suggest that at least some aspects of Levelt et al.'s model are relevant for comprehension as well as production.

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Lexical access as a brain mechanism*

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Abstract: The following questions are addressed concerning how a theory of lexical access can be realized in the brain: (1) Can a brainlike device function without inhibitory mechanisms? (2) Where in the brain can one expect to find processes underlying access to word semantics, syntactic word properties, phonological word forms, and their phonetic gestures? (3) If large neuron ensembles are the basis of such processes, how can one expect these populations to be connected? (4) In particular, how could one-way, reciprocal, and numbered connections be realized? and, (5) How can a neuroscientific approach for multiple access to the same word in the course of the production of a sentence?

A processing model of lexical access such as the one described in detail in the target article is not necessarily a theory about brain mechanisms. Nevertheless, it may be fruitful to ask how the model can be translated into the language of neurons.

Feedback regulation is necessary! The brain is a device with extreme plasticity. Early in ontogenesis, neurons rapidly grow thousands of synapses through which they influence their neighbors and, in turn, receive influence from other neurons. These synaptic links become stronger with repeated use. Therefore, a particular brain-internal data highway that initially consists of a few fibers, may later include thousands or millions of cables with weak synaptic links, and may finally exhibit a comparably large number of high-impact connections. In this case, the same input to the system will lead early on to a minimal wave of activity, but finally lead to a disastrous breaker. A system with such an enormous variation of activity levels requires a regulation mechanism in order to function properly (Braitenberg 1978). The task of this mechanism would be to enhance or depress the global level of activity to keep it within the limits of optimal neuronal functioning.

A simple way to regulate activity in a neuronal system is to monitor activity levels of all neurons, calculate their sum, and provide an additional input to the system that is excitatory if this sum is small (to prevent extinction of excitation), but inhibitory if it is large (to prevent overactivation). Thus, a mechanism of inhibition (or disfacilitation) appears necessary in any brainlike model.

Levelt, Roelofs & Meyer (Levelt et al.) state that their model does not include inhibition (sect. 3.2.2) and the fact that it does not may be interpreted as one of their minimal assumptions – evidencing a research strategy guided by Ockham's razor. Certainly, looking at the theory in abstract space, the assumption of inhibitory links would be an additional postulate that made it less economical and therefore less attractive. However, considering the brain with its well-known intracortical and striatal inhibitory neurons that are likely to be the basis of feedback regulation (Braitenberg & Schüz 1991; Fuster 1994; Wickens 1993), it does not seem desirable to propose that inhibitory mechanisms are absent in a model meant to mirror brain functioning.

Would this mean that the theory proposed by Levelt et al. is unrealistic from the perspective of brain theory? Certainly not. Although such mechanisms are not explicitly postulated or wired into the network (and therefore do not affect activation spreading), they kick in at the level of node *selection* where Luce ratios are calculated to obtain the probability with which a preactivated representation is selected (fully activated, so to speak). The probability that a particular node is selected depends upon its actual activity value *divided by* the sum of the activation values in a particular layer. Because the calculation performed is very similar to what a regulation device would do, one may want to call this implicit, rather than explicit, inhibition (or regulation). To make it explicit in the network architecture, an addition device in series with numerous intra-layer inhibitory links would have to be introduced. Thus, the model includes inhibition – although on a rather abstract level – and this makes it more realistic from the neurobiological perspective.

Brain loci of lexical access. Where in the brain would one expect the proposed computation of lexical concept, lexical syntax (lemma), word form, and phonetics? Most likely, phonological plans and articulatory gestures are wired in primary motor and premotor cortices in the inferior frontal lobe. The percepts and motor programs to which words can refer probably correspond to activity patterns in various sensory and motor cortices and thus may involve the entire cortex or even the forebrain. More specificity is desirable here; for example, words referring to movements of one's own body are likely to have their lexical concept representations localized in motor cortices and their vicinity, while lexical concepts of words referring to objects that one usually perceives visually should probably be searched for in visual cortices in occipital and inferior temporal lobes (Pulvermüller 1996; Warrington & McCarthy 1987).

Between phonetic-phonological and lexical-semantic representations the model postulates lemmas whose purpose can be considered to be three-fold: (1) not only do they glue together the meaning and form representations of a word, but, in addition, (2) they bind information about the word's articulation pattern and its sound image. Furthermore, (3) lemmas are envisaged to store syntactic knowledge associated with a word.

Intermediary neuronal units mediating between word form and semantics – the possible counterparts of lemmas have been proposed to be housed in the inferior temporal cortex (Damasio et al. 1996). The present theory would predict that lesions in the "lemma area" lead to a deficit in accessing syntactic knowledge about words (in addition to a deficit in naming). However, lesions in inferior temporal areas can lead to a category-specific naming deficit while syntactic knowledge is usually spared. Hence, it appears unlikely that lemmas are housed in the inferior temporal lobe. Is there an alternative to Damasio's suggestion?

One of the jobs of a lemma is to link the production network to the perception network (sect. 3.2.4). On the receptive side, sound waves and features of speech sounds activate neurons in the auditory cortex in the temporal lobe, and in order to store the many-many relation between acoustic phonetic features and articulatory phonetic features, it would have advantages to couple the respective neuron populations in auditory and motor cortices. Such coupling, however, is not trivial, because, for example, direct neuroanatomical connections between the primary motor and auditory cortices are rare, if they exist at all. Therefore, the connection can only be indirect and the detour to take on the articulatory-

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