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War and Peace: Morphemes and Full Forms in a Noninteractive Activation Parallel Dual-Route Model

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This article introduces a computational tool for modeling the process of morphological segmentation in visual and auditory word recognition in the framework of a parallel dual-route model. © 1999 Academic Press

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INTRODUCTION

Current models of visual and auditory word recognition make use of the mechanism of inhibition between lexical representations to ensure that ultimately one lexical representation will be recognized. In models such as Shortlist (Norris 1994) or the multiple read-out model of Grainger and Jacobs (1996), lexical representations compete with each other such that a single representation wins the war between lexical candidates.

These models capture important aspects of the lexical processing of monomorphemic words. Assuming that morphologically complex words are recognized via their full-form representations only, this ''competition-to-death'' mechanism can be straightforwardly extended to cover both simple and complex words. However, these models fail to meet the productivity constraint (Frauenfelder & Schreuder, 1991), as they cannot explain how novel complex words are recognized. Moreover, these models also fail to explain the experimental evidence for constituent-based recognition for existing complex words. Recent studies (Baayen, Dijkstra, & Schreuder, 1997; Baayen, Burani, & Schreuder, 1997; Bertram, Laine, & Karvinen, in press) suggest that lexical access is attempted in parallel not only on the basis of the full form of a complex word, but also on the basis of its constituents.

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Unfortunately, current competition models cannot be straightforwardly extended to incorporate the parallel dual-route architecture. The competition-to-death mechanism enforces that a single victor will emerge from the competition process in which all lexical representations, including full forms and their constituents, are at war.

We present a new computational tool for the modeling of visual and auditory morphological processing in the parallel dual-route architecture, without giving up the concept of lexical competition. Our model is not a connectionist model, nor an interactive activation model. Instead, it is a mathematical meta-model that captures the functional structure of lexical processing while remaining agnostic with respect to the ultimate implementation of computational models for the brain itself.

MODEL ARCHITECTURE

Schreuder and Baayen (1995) distinguish three stages in morphological processing in comprehension: segmentation, licensing, and composition. In the segmentation stage, access representations of morphemes and full forms are activated depending on the extent to which they match the input. In the licensing stage, the system checks whether the activated representations provide a full spanning of the input and, if so, whether a given combination of morphemes is licensed given their subcategorization properties. During the composition stage, the meaning of the complex word is computed on the basis of its constituents. Our model currently implements the segmentation stage and the first part of the licensing stage.

The model's lexicon consists of access representations for morphemes and full forms. Each access representation has its own resting activation level, its relative token frequency in the input morpheme frequency list supplied by the user. Activation levels in the model are probabilities of identification. Activation levels may rise and decay. Activation levels rise when, at a given time-step, new matching information becomes available. Activation levels decay either when no more matching information can be extracted from the input or when threshold activation level has been reached. Because activation levels are probabilities, lexical competition needs no specific mechanism of its own. When one access representation achieves a higher activation level, the other access representations by necessity obtain lower activation levels. Likewise, a decaying access representation frees activation probability for other representations.

Access representations that have reached threshold are copied into a short-term memory buffer, which feeds the licensing process. Thanks to this memory buffer, there is no need to require lexical competition ‘‘to-death’’ with one winning representation only. Instead, various representations may reach threshold, including representations that provide a reasonable match with the input without being a real morphological constituent. It is left to the licensing process to find complete spannings that satisfy the subcategorization requirements of the constituents in the spanning. Thus there is lexical competition in our model, but this competition is resolved in peace.

The architecture described thus far is common to both the visual and the auditory modalities. The two modalities differ with respect to how information concerning the similarity between an access representation and the input becomes available. In the visual modality, our present simplifying assumption is that the complete visual input is available from the start. The similarity between an access representation and the input is evaluated by means of a similarity metric based on an edit distance. The greater the similarity, the longer an access representation will remain active.

In the auditory modality, with each time-step a new phoneme becomes available to the system, initializing a new cohort of potential candidates beginning with that phoneme. As soon as mismatching information becomes available for such candidates, they enter the decay process. The model assumes that strong syllables are more likely to set up such new cohorts than weak syllables, following Cutler and Norris (1988). For a detailed description and a formal definition of the model, the reader is referred to Baayen, Schreuder, and Sproat (1999).

EXAMPLES OF ACTIVATION PATTERNS

Figure 1 presents some examples of activation curves generated by our model. The top panel plots activation probability p as a function of model time t for the Dutch word *snelheid* (‘‘speed’’ from *snel,* ‘‘quick,’’ and *-heid,* ‘‘-ness’’) in the auditory modality using a realistic input lexicon of roughly 40,000 entries. The length of a phoneme on the time scale is 4 time-steps. Thus, word offset for *snelheid* (/snElhKt/ in the DISC phonetic alphabet) is at $t = 28$. The first access representation to reach threshold is the base *snel* (/snEl/), followed by *snelheid* (/snElhKt/) at $t = 18$. At this point in time, the full form, which has been a matching candidate from word onset, has become the most likely candidate, long before word offset. Following the decay of *snelheid,* other access representations reach threshold, such as the suffix *-heid* (/hKt/), the pronoun *hij* (/hK/), and the *-t,* which can be an inflectional suffix on verbs or the clitic corresponding to the neuter definite article *het.* Thus the first full spanning to arrive in the short-term memory buffer is the full form *snelheid,* followed shortly after word offset by the morphological parsing *snel+heid* at $t = 29$ and the syntactic parsing *snel+hij+t.* Both parsings are grammatical, the former being a legitimate combination of the de-adjectival suffix *-heid* with an adjectival base, the latter being part of a possible sentence such as

Ik weet niet hoe snel (/snEl/) hij (/hK/) ’t (/t/) kan doen.
I do not know how quickly he can do it.

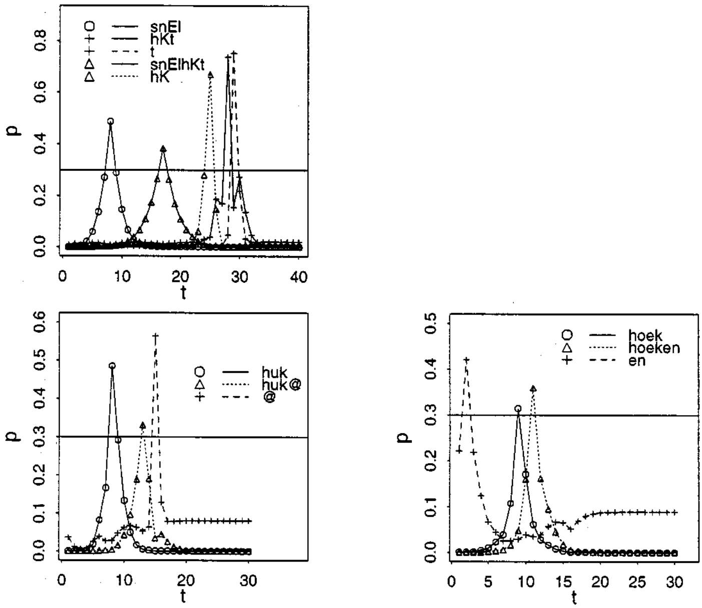

FIG. 1. Examples of activation patterns for Dutch complex words.

Note that our model does not make a principled distinction between the segmentation of words into morphemes and the segmentation of words in a sentence. The principal difference between morphology and syntax in our model is that most words in a language like Dutch have their own access representations in the lexicon, whereas sentences only rarely have their own representations.

The bottom panels show activation patterns for the plural noun *hoek+en*, ‘‘corner.’’ For the auditory input */huk@/*, the first access representation to reach threshold is the base word */huk/*, followed by the full form */huk@/*, which has been in the initial cohort from the start. After the word-final schwa (*/@/*) has become available in the input, the plural suffix (*/@/*) reaches threshold. Due to the sequential nature of the speech input and the presence of a full-form representation in the model’s lexicon, the direct route wins the race well ahead of the parsing route.

In the visual modality, the assumption that the complete input is available from the start leads to a different pattern in which the high-frequency access representation of the suffix *-en* quickly reaches threshold, followed by that of the base. The full-form access representation reaches threshold last, being less frequent than its base. Thus, the consequences of different theoretical assumptions about morphological processing in the auditory and visual domains are made visible.

DISCUSSION

We have sketched a new computational tool for modeling morphological processing, aiming for a functional characterization. Following-up on the mathematical model of Baayen, Dijkstra, and Schreuder (1997), the present computational tool implements the segmentation stage of morphological processing in an activation framework.

We take segmentation to be a fully bottom-up, autonomous process of pattern recognition that is blind to the linguistic properties of the access representations, such as whether an access representation represents a word or a morpheme or a complex form. It is only at the later stages of lexical processing, after a full spanning has been obtained, that linguistic properties of the elements in the full spanning begin to play a role.

From a computational point of view, the model provides an interesting means of reducing the ambiguity problem. Complex words often have several possible segmentations. For instance, the Dutch word *belangstellende,* ''interested person,'' has 89 possible segmentations into sequences of Dutch morphemes. Many such segmentations are spurious parses that are not licensed by the subcategorization properties of the morphemes. Other segmentations are possible but implausible parses. Interestingly, the first set of full spannings to become available in our model is small (only four spannings) and includes the correct segmentation. This suggests informally that our psychologically motivated approach to the problem of ambiguity resolution is worth pursuing as an alternative to the Markovian probabilistic models that are the state-of-the-art techniques in computational linguistics.

Finally, note that the model's behavior is not only determined by its parameters, but also by its input lexicon. The kind of elements that appear in the input lexicon play a decisive role. In fact, our parallel dual-route model can be turned into a single-route model by either removing full forms from the lexicon or by removing affixes. Thus, our model can be used to investigate in more detail than has been possible the consequences of the assumptions of verbal models of morphological processing.

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