A spreading-activation theory of lemma retrieval in speaking*

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Abstract


This paper presents a spreading-activation theory of conceptually driven lemma retrieval – the first stage of lexical access in speaking, where lexical items specified with respect to meaning and syntactic properties are activated and selected. The mental lexicon is conceived of as a network consisting of concept, lemma, and word-form nodes and labelled links, with each lexical concept represented as an independent node. A lemma is retrieved by enhancing the activation level of the node representing the to-be-verbalized concept. This activation then spreads towards the lemma level, and the highest activated lemma node is selected. The theory resolves questions such as the hypernym problem (Levelt, 1989). Furthermore, a computer model that implements the theory is shown to be able to account for many basic findings on the time course of object naming, object categorization, and word categorization in the picture-word interference paradigm. In addition, non-trivial predictions regarding the time course of semantic facilitation for hypernyms, hyponyms, and cohyponyms are experimentally tested, and shown to be valid.

1. Introduction

A central problem in speech production concerns the process of lexical access.

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During normal conversation, a speaker retrieves just the right word for a concept to be verbally expressed, both fast—up to five words per second—and accurately—with less than one whole-word error per 2000 words (Levelt, 1989). This is an enormous achievement given the vastness of the mental lexicon; it is conjectured that a speaker has an active vocabulary of some 30,000 words (the number varies greatly from speaker to speaker). How is such efficient word retrieval accomplished by a speaker?

This paper presents a theory of the first stage of lexical access in speaking, called lemma retrieval, where lexical items specified with respect to meaning and syntactic properties are activated and selected (the second stage is word-form encoding and will not be addressed). To set the stage for the exposition of the theory, I will first discuss the role of lemma retrieval in speech production. Next, I will distinguish between computational decomposition and non-decomposition approaches to lemma retrieval, and point to an important class of retrieval (i.e., convergence) problems for the existing decomposition theories, supporting the non-decompositional approach taken in this paper. Finally, I will briefly describe the experimental paradigm that has been used in initial tests of the theory: the picture-word interference paradigm. In the remainder of the paper, the theory will be outlined, and tested by computer simulation and empirical experiment. My aim is to show that the proposed theory resolves the retrieval problems in a simple fashion, and that it can account—both qualitatively and quantitatively—for many basic empirical phenomena associated with conceptually driven naming.

1.1. Lemma retrieval in speech production

Psycholinguists usually hold that speech production involves three types of mental processes. First, speaking starts with conceptualization processes, specifying which concepts are to be expressed verbally. Second, formulation processes select appropriate words for these concepts, and build a representation of (a) the syntactic structure (in case of sentence production) and (b) the sound structure of the utterance. Third, articulation processes realize the latter as overt speech (cf. Bock, 1982, 1986; Dell, 1986; Garrett, 1975, 1988; Kempen, 1977; Kempen & Hoenkamp, 1987; Levelt, 1983; for a review of the processes underlying speaking, see especially Levelt, 1989).

expressed. The latter is called the message (Garrett, 1975; Levelt, 1989) or the interfacing representation—the representation that interfaces between thought and language (Bock, 1982). Lemmas represent the meaning and the syntactic properties of a word (see Levelt, 1989, for a detailed description). For instance, the lemma of the word dog specifies the conceptual conditions for the appropriate use of the word, and indicates, inter alia, that the word is a noun. Lemma retrieval is a crucial component of the syntactic encoding process. The building of a phrasal, clausal, or sentential structure (e.g., making the noun dog head of a noun phrase) requires the syntactic part of lemmas. Word-form encoding is the process by which an articulatory program for the word is constructed. This involves retrieving its morpheme(s) and speech segments, and linking them to categorically labelled slots in word-form frames (Dell, 1986; Garrett, 1975; Levelt, 1989; Shattuck-Hufnagel, 1979). For example, the syllable frame for dog is filled with the retrieved segments /d/, /a/ and /g/. A final step in word-form encoding involves addressing stored syllable programs, which will control the articulatory movements (Levelt, 1989). Following Kempen and Huijbers (1983), the mental representation of word-form information will be referred to as the lexeme.

The assumption of two accessing steps, instead of one for the whole word, is supported by experimental findings on speech latencies and word-order preferences (e.g., Bock, 1986; Kempen & Huijbers, 1983; Levelt & Maassen, 1981; Levelt et al., 1991a; Schriefers, Meyer, & Levelt, 1990), tip-of-the-tongue studies (e.g., Brown & McNeill, 1966; Jones & Langford, 1987), speech-error data (e.g., Dell, 1986; Fromkin, 1971; Garrett, 1975, 1976, 1980, 1988), and data from aphasia (e.g., Butterworth, 1989; Saffran, Schwartz, & Marin, 1980). For an extensive discussion of whether lemma retrieval and word-form encoding are not only distinct, but also discrete (i.e., temporally nonoverlapping) processes, I refer to Dell and O'Seaghdha (1991) and Levelt et al. (1991b).

1.2. Decomposed retrieval, yes or no?

The process of lexical access has not received as much attention in the study of language production as it has in the study of language comprehension. Theories of lexical access in speaking primarily address the process of word-form encoding (e.g., Dell, 1986, 1988; Meyer, 1990; Shattuck-Hufnagel, 1979; Stemberger, 1985). Although typically some assumptions are made about lemma retrieval (e.g., Bock, 1982; Brown & McNeill, 1966; Butterworth, 1989; Fay & Cutler, 1977; Fodor, 1976; Garrett, 1982; Morton, 1969; Oldfield, 1966; Stemberger, 1985), only a few theories address this process in depth (Dell & O'Seaghdha, 1991; Goldman, 1975; Miller & Johnson-Laird, 1976; for an extensive review, see Levelt, 1989).

Theories of lemma retrieval can be divided into two broad classes: decomposi-
tional and non-decompositional. Decompositional theories claim that semantically complex words (i.e., words whose meaning can be further analysed into more elementary concepts) are retrieved on the basis of a combination of primitive concepts (e.g., Bock, 1982; Dell, 1986; Dell & Reich, 1981; Dell & O'Seaghdha, 1991; Goldman, 1975; Miller & Johnson-Laird, 1976; Morton, 1969; Stemberger, 1985). They argue, for example, that the lemma of *father* is retrieved on the basis of representations like MALE(X) and PARENT(X, Y). In contrast, non-decompositional theories (cf. Collins & Loftus, 1975; Fodor, 1976; Fodor, Fodor, & Garrett, 1975; Fodor, Garrett, Walker, & Parkes, 1980; Garrett, 1982; Kintsch, 1974) assume that an abstract representation FATHER(X, Y) is used to retrieve *father*, and that properties such as MALE(X) and PARENT(X, Y) are specified outside the message, in semantic memory.1

Whereas both decomposition and non-decomposition theories seem to be able to account for several major empirical facts on word meaning quite well (e.g., Collins & Loftus, 1975; Smith, Shoben, & Rips, 1974), at least one class of problems relevant to lemma retrieval seems to require a non-decompositional approach. When a concept has to be expressed, and the mental lexicon contains the appropriate word, precisely that word's lemma should be retrieved and no other (Levelt, 1989). But the retrieval procedures proposed by the existing decompositional theories fail to do so. Hypernymy and word-to-phrase synonymy are especially troublesome (Levelt & Schriefers, 1987; Levelt, 1989; Roelofs, in preparation). If the meaning of word *a* implies the meaning of word *b*, *b* is a hypernym of *a*, and *a* is a hyponym of *b* (Cruse, 1986; Lyons, 1977). When the conceptual conditions of a hyponym (e.g., *father*) are met, then those of its hypernyms (e.g., *parent*) are automatically satisfied as well. Therefore, in accessing a particular word, all its hypernyms should also be retrieved (Levelt, 1989). The existing decompositional theories cannot explain how the retrieval process converges on the appropriate lemma. Word-to-phrase synonymy poses similar problems. According to decompositional theories, utterances such as *... is a father* and *... is a male parent* will have one and the same underlying conceptual structure (Fodor, 1976). But how, then, does the retrieval mechanism know to select one lemma (in the former case) or several lemmas (in the latter case)?

For a theory without decomposition of lexical-concept representations, hypernymy and word-to-phrase synonymy pose no difficulties. MALE(X), PARENT(X, Y), and FATHER(X, Y) are computational primitives, and are made part of the message to retrieve, respectively, *male*, *parent*, and *father* (for

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1The decomposition at issue here concerns the computational primitives of the speech production system at the message level. Computational primitives, such as FATHER(X, Y) in a non-decompositional approach, are not necessarily also developmentally primitive (i.e., a starting point for concept acquisition) or definitionally primitive (i.e., without a definition) (for a discussion, see Carey, 1982; Fodor, 1976, p. 152; Fodor et al., 1980, p. 313; Roelofs, in preparation).
the feasibility of syntactic encoding without lexical decomposition see, for example, De Smedt, 1990; Kempen & Hoenkamp, 1987).

1.3. Theory and experimental paradigm

Below, a spreading-activation theory will be proposed that is designed to handle conceptually driven lemma retrieval. Following Dell (1986), Dell and Reich (1981), Harley (1984), Stemberger (1985), and others, the mental lexicon is conceived of as a network. It is assumed to consist of (a) a conceptual stratum with concept nodes and links, (b) a syntactic stratum with lemma nodes and links, and (c) a word-form stratum with input-lexeme and output-lexeme nodes and links. To solve the convergence problems mentioned (and variants of them, see Roelofs, in preparation), I assume that conceptual component nodes are only indirectly linked to lemma nodes, via non-decomposed concept representations. Within the message, there is no lexical decomposition. This is in contrast to Dell, Stemberger, and others, and in line with the preposals by Collins and Loftus, and Fodor, Garrett, and colleagues. A lemma is retrieved by enhancing the activation level of the node of the to-be-verbalized concept (similar to giving it signalling activation in the theory of Dell, 1986). This activation then spreads towards the syntactic stratum, and the highest activated lemma node is selected.

The theory will be applied to empirical findings on object naming, object categorization, and word categorization (among the simplest forms of conceptually driven word retrieval), both informally and by computer simulation. The simulations concern the time course of lemma retrieval in the so-called picture-word interference paradigm (cf. Glaser & Düngelhoff, 1984; Glaser & Glaser, 1989; La Heij, 1988; Lupker, 1979; Rosinski, 1977; Schriefers et al., 1990; Smith & Magee, 1980). Subjects have to name pictured objects (e.g., they have to say dog to a pictured dog) and ignore so-called distractor words. A distractor word is a written word superimposed on the picture or a spoken word presented via headphones. The naming response is affected depending on, inter alia, the temporal relationship (the stimulus onset asynchrony or SOA) and the content relationship between picture and word. Usually, the distractor is presented just before (e.g., -400, -300, -200 or -100 ms), simultaneously with, or right after (e.g., +100, +200, +300, or +400 ms) picture onset, and is either semantically related to the pictured object (e.g., distractor fish, henceforth the REL condition) or semantically unrelated (e.g., distractor tree, henceforth the UNR condition). Alternatively, the subjects are asked to refer to the picture or to the word printed in the picture by producing a hypernym—called, respectively, picture categorization and word categorization. For example, they have to say animal to a depicted dog, while trying to ignore the word printed in the picture. Or they have to say animal to the word dog and ignore the picture. Typically, one observes semantic
inhibition (i.e., naming latencies are slower for REL than for UNR) at SOA ∈ [-100, +100] for picture naming, semantic facilitation (i.e., naming latencies are faster for REL than for UNR) at SOA ∈ [-400, -100] for picture categorization, and even more semantic facilitation at SOA ∈ [-400, +200] for word categorization (Glaser & Düngelhoff, 1984; Glaser, this issue).

Testing the theory on the basis of object naming, object categorization, and word categorization may seem rather restrictive. However, to date, these tasks have provided the most detailed information on the time course of conceptually driven naming (alone or in combination with an auxiliary task; see Levelt et al., 1991a). For a discussion of the importance of time-course analyses in studying lexical access in speaking, I refer to Levelt (1989), Levelt et al. (1991a, 1991b), and Schriefers et al. (1990); for a discussion of the importance of SOA functions in testing a process model, see especially Vorberg (1985).

One might be inclined to argue that naming and categorization are not suitable testing grounds for a theory of lemma retrieval, because the syntactic properties of a word do not play a role in naming isolated objects. Could not a concept be directly mapped onto a word form, as is advocated by Collins and Loftus (1975) and many theorists in the field of picture-word processing (cf. Glaser & Glaser, 1989; Nelson, Reed, & McEvoy, 1977; Potter, 1979; Seymour, 1979; Smith & Magee, 1980; Snodgrass, 1984; Theios & Amrhein, 1989)? A central assumption in this paper is that, in naming and categorization, speakers cannot bypass lemma retrieval, just as they cannot simply retrieve but have to construct articulatory programs (cf. Dell, 1986; Levelt, 1989). Both lemma retrieval and word-form encoding are of primary use in the production of connected speech. Lemma retrieval makes available the syntactic properties of words for the syntactic encoding process. Word-form encoding enables a speaker to resyllabify words: to enhance the fluency of articulation, a speaker often combines neighbour words in the utterance, which leads to a syllabification of words that differs from the syllabification specified in the mental lexicon. If articulatory programs were ready-made wholes, then such resyllabification of words would not be possible (Levelt, 1989).

Thus, it is assumed that there is only a single route from word meaning to word form, instead of one via a lemma, taken during sentence production, and another one bypassing lemmas, taken in the production of single words (for empirical support see, for example, Kempen & Huijbers, 1983). Moreover, lemma retrieval is claimed to be responsible for the semantic effects in the picture–word interference paradigm (cf. Schriefers et al., 1990), and not word-form retrieval, as is claimed by Glaser and Glaser (1989), La Heij (1988), and La Heij, Happel, and Mulder (1990). In a picture–word interference experiment with spoken distractor words, Schriefers et al. (1990) obtained a lexical semantic effect at a negative SOA (-150 ms), and a word-form effect at later SOAs (viz., 0 and +150 ms). For example, the naming of a pictured dog was inhibited at the early SOA by the
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semantically related distractor *fish* compared to the semantically unrelated distractors *tree* and *doll*. By contrast, the naming response was facilitated at the later SOAs by the phonologically related distractor *doll* compared to the phonologically unrelated distractors *fish* and *tree*. If one assumes, for object naming, a direct mapping from concepts onto word forms, one should not get an early lexical semantic effect and a late word-form effect. Schri&rs et al. provided evidence that the semantic effect was indeed *lexical*: in a recognition task without naming the effect disappeared, as is typical for Stroop(-like) effects (for a review see, for example, La Heij, 1988). If we assume that a concept is mapped onto a word form via a lemma then, initially, semantic competitors could be active at lemma level and cause the early *lexical* semantic effect whereas, later on, the word form of the target becomes encoded, causing the word-form effect. (For further evidence, see Levelt et al., 1991a.)

1.4. *A brief overview of the remainder*

The remainder of this paper is organized as follows. In section 2, I will explain the theoretical assumptions. In section 3, the theory is applied (a) to object naming, object categorization, and word categorization by computer simulation, and (b) informally, and very briefly, to speech errors (i.e., word blends, substitutions, and exchanges). In addressing naming and categorization, I will mainly concentrate on findings obtained by Glaser and Döngelhoff (1984) and Glaser and Glaser (1989), because their time-course studies are among the most comprehensive available in the literature: they include the speech latencies for picture naming, picture categorization, and word categorization with both picture distractors as well as word distractors over an extended range of SOAs (i.e., −400 up to +400 in steps of 100 ms). Slips of the tongue will be addressed, because they have been central in developing theories of speech production, and, therefore, may not be ignored by the new theory proposed. In section 4, some novel, and non-trivial, empirical predictions of the theory are tested in a new experiment, and shown to be valid. And finally, section 5 comprises a summary and conclusions.

2. *Theoretical assumptions*

2.1. *General architecture*

I will assume that in the naming of a perceptually given object (at least) four processing stages are involved (see Figure 1). First, there is the stage of object identification based on perceptual input (conceptual identification of the stimulus). The target representations of this processing level are concepts. Second, there is
Figure 1. Stages of mental processing engaged in the picture–word interference paradigm. Boxes denote processing stages, and arrows indicate the relevant flow of information through the system.

the stage of lemma retrieval (response selection). Third, there is the stage of word-form encoding (response programming). The fourth stage involves articulating the name of the object (response execution), resulting in overt speech. My theoretical claims will be restricted to the second stage. They will concern how a lemma is retrieved, given a concept to be verbalized.²

Figure 1 also indicates the mental stages assumed to be engaged in the picture–word interference paradigm; the perceptual stages that process pictures and words are shown on the left. The conceptual identification of an object involves mapping a representation of the object's form onto a concept, preferably a basic-level one (Jolicoeur, Gluck, & Kosslyn, 1984; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). Categorization of the object (i.e., a dog as animal), then, requires the retrieval in memory of its superordinate (Jolicoeur et al., 1984). The information flow from conceptual identification to lemma retrieval and vice versa is continuous (for empirical support, see Humphreys, Riddoch, & Quinlan, 1988; Schriefers, 1990). No specific claims will be made about the other

²A theory of lemma retrieval presupposes that speakers have decided what to say, that is, have encoded a message, at the level of lexical concepts either in terms of conceptual components (in a decomposition view) or not (in a non-decomposition view). A theory of message encoding has to explain how speakers decide what to say, in particular, what kind of speech act to make and what conceptual content (i.e., conceptual component nodes or concept node) to include in the message to reach their communicative goals (for a review, see Levelt, 1989).
perceptual and production stages. A written word will activate both its lemma and its articulatory program, as is shown by language comprehension research (cf. Rayner & Pollatsek, 1989) and the research on picture-word processing (cf. Nelson et al., 1977; Potter, 1979; Snodgrass, 1984). The existence of a direct route from written word to articulatory program is also indicated by interference effects obtained with the word pronunciation task. Glaser and Glaser (1989) and La Heij et al. (1990) observed an inhibitory effect of word distractors on reading a word aloud. For example, both fish and tree slowed down the reading aloud of dog (relative to pronouncing dog without a distractor word). However, there was no additional effect of semantic relatedness: fish (REL) did not cause more inhibition than tree (UNR). Furthermore, if instead of a distractor word a picture of a fish or tree was given, almost no effect on reading dog was observed (Glaser & Dungelhoff, 1984). These findings suggest that a word can be read aloud without explicitly selecting the word's lemma.

2.2. The memory structure of lexical entries

Figures 2 and 3 illustrate the main assumptions about the memory representation of a word. Figure 2 shows the structure of a single lemma. It illustrates the types of information linked to a lemma node: the sense of the word, its syntactic properties, and its input and output lexemes. Figure 3 shows a fragment of the lexical network representing the Dutch words hond (dog) and dier (animal).

First, at the conceptual stratum, there are concept nodes and conceptual links storing the meanings of the words. Each node represents a single concept, such as DOG, ANIMAL, and BARK (cf. Collins & Loftus, 1975; Fiksel & Bower, 1976; Norman & Rumelhart, 1975; Shastri, 1988). The links between the nodes are labelled pointers, which express a relationship between two concepts. For instance, the IS-A link indicates that DOG is a subtype of ANIMAL, and the CAN link specifies that a DOG can BARK. Links differ in their accessibility (cf. Collins & Loftus, 1975), which is determined by a weight (a positive real-valued number) on the link. Weights will be explained in the next section. Furthermore, outside the lexical network proper, there are nodes for the visual form of the objects.

In a network theory with labelled links (or pointers) such as proposed in this paper, a discreteness of stages may be obtained by limiting the availability of certain links for the spreading process. For example, if the link (pointer) between a lemma node and a word-form node only becomes available upon selection of the lemma node, then lemma retrieval and word-form encoding will be discrete (i.e., temporally non-overlapping) processes. In experimental studies of the time course of object naming, Levelt et al. (1991a) and Schriefers et al. (1990) obtained data fully compatible with a discreteness of lemma retrieval and word-form encoding. As already indicated, for an extensive discussion the reader might consult Dell and O'Seaghdha (1991) and Levelt et al. (1991b).
Figure 2. Structure of a lemma.

Figure 3. Fragment of the lexical network for the Dutch words hond (dog) and dier (animal). For an explanation, see text.
denoted by the words. These form representations are involved in shape-based object identification.

Second, at the syntactic stratum, there are *lemma* nodes, and nodes and labelled links which correspond to the words' syntactic properties, such as gender (GENDER or G: Ne = neuter, Ma = masculine) and syntactic category (SYNCAT or SC: N = noun). Third, at the word-form stratum, there are *input-lexeme* (INLEX) nodes and links for the orthography, and *output-lexeme* (OUTLEX) nodes and links for the morpho-phonological properties of the words in speaking. The output-lexeme part of the network is involved in word-form encoding (cf. Dell, 1986, 1988; Stemberger, 1985), and the input-lexeme part is involved in visual word-recognition (cf. McClelland & Rumelhart, 1981).

2.3. The spreading of activation and the selection process

Information is retrieved from the network by means of spreading activation (cf. Collins & Loftus, 1975; Dell, 1986). Activation is taken to be a positive real-valued quantity, spreading according to the equation

\[
a(m, t + \Delta t) = a(m, t)(1 - d) + \sum_{n \in N} w(n, m)a(n, t)
\]

where \(a(m, t)\) is the activation level of node \(m\) at point in time \(t\), \(d\) is a decay rate \((0 < d < 1)\), and \(\Delta t\) is the duration of a time step. The rightmost term denotes the amount of activation node \(m\) receives between \(t\) and \(t + \Delta t\), where \(a(n, t)\) is the output of neighbour node \(n\) (the output of \(n\) is equal to its level of activation), \(N\) the set of direct neighbour nodes \(n\) of \(m\), and \(w(n, m)\) the weight on the link between nodes \(i\) and \(m\). A weight determines the proportion of activation sent along the link.

In spontaneous speech, the retrieval of a lemma is a very simple process. The activation level of the node of the to-be-verbalized concept (flagged as being part of the message, as in the theory of Dell, 1986) is enhanced, followed by a spread of the activation from the conceptual stratum towards the syntactic stratum, and a selection of the highest activated lemma node.

In a picture-word interference experiment the selection is more complicated. The retrieval system must select the lemma activated by the picture, and prevent selection of the lemma activated by the distractor word. To solve this indexing problem I will assume, following Collins and Loftus (1975), that when activation spreads along the links of the network it leaves *activation tags* at each node reached, specifying the *source* of the activation (see also Charniak, 1983; Hendler, 1989; Quillian, 1967). So, in a picture-word interference experiment, there are picture tags and word tags. The lemma nodes that are permitted responses in
the experiment receive a *flag* indicating that they are members of the response set. (In the experiments to be discussed, subjects studied a booklet showing the pictures and the names to be used, before the experiment began; I assume that during that period lemmas became flagged as permitted responses.) The determination of the response node is based on the *intersection* of the tag originating from the target source (e.g., the picture in picture naming) and a response-set flag on one of the lemma nodes. The node at which the intersection is established first will be the target lemma.

I will assume that an intersection is by itself insufficient to trigger a response. The activation level of the target lemma node must also exceed that of the other nodes in the response set by some critical amount. Once this amount has been reached, the actual selection is a random event. Let $T$ denote time, let $s$ be the $s$th time step, $\Delta t$ the duration of a time step, and $t$ a particular moment in time, where $t = (s - 1) \Delta t$, and $s = 1, 2, \ldots$. The probability that the target node $m$ will be selected at $t < T \leq t + \Delta t$ given that it has not been selected at $T \leq t$ (and provided that an intersection has been established and the critical amount has been reached) is given by the ratio (cf. Luce, 1959)

$$p(\text{selection } m \text{ at } t < T \leq t + \Delta t \mid \neg \text{selection } m \text{ at } T \leq t) = \frac{a(m, t)}{\sum_{e \in \mathcal{E}} a(e, t)}$$

(2)

The index $e$ ranges over the lemma nodes of all the targets and distractors occurring in an experiment, irrespective of response-set membership. Thus, the probability of actually selecting the target lemma node depends on the activation state of other salient lemma nodes in the mental lexicon. The selection ratio, hereafter referred to as the *Luce ratio*, equals the hazard rate $h(s)$ of the process of lemma retrieval at time step $s$ (cf. Luce, 1986; McGill, 1963; Townsend & Ashby, 1983). It is the probability that the retrieval of lemma $m$ is completed at $t < T \leq t + \Delta t$ given that it is not already completed. When no intersection has been established and/or the critical difference has not been exceeded, then $h(s) = 0$.

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If there are no a priori restrictions on the responses, the intersection mechanism might work as follows. Following Collins and Loftus (1975), assume that a person can diffusely activate (prepare) an entire stratum of the network, here the syntactic stratum. If the resulting activation tags do not spread but stay at their nodes (which makes sense, because they come from an unspecific source of activation), the target lemma node could be determined by the intersection of the target-source tag (picture or word) and one of these tags.
3. Application of the theory

3.1. Picture naming, picture categorization, and word categorization

In this section, I will show that the proposed theory can account for many empirical findings relevant to conceptually driven lemma retrieval. The findings are from studies of object naming, object categorization, and word categorization. First, I will briefly describe a computer model embodying the main theoretical assumptions. Next, I will present results from computer simulations of the time course (i.e., the SOA functions) of picture naming with a word distractor, picture categorization with a word distractor, and word categorization with a picture distractor.

In each simulation the procedure was as follows. For a particular experimental condition the expected lemma retrieval time $E(T)$ was computed on the basis of the activation equation (Equation 1), the selection ratio (Equation 2), and

$$E(T) = \sum_{s=1}^{\infty} h(s) \left\{ \prod_{j=0}^{s-1} (1 - h(j)) \right\} s \Delta t$$

where $h(s)$ is the hazard rate function of lemma retrieval in the model, $h(0) = 0$, and $1 - h(s)$ the probability that $m$ is not selected at time step $s$ given that it has not already been selected. The derivation of the formula for $E(T)$ is given in the Appendix.

Figure 4 illustrates the network configuration used in the simulations. The

![Diagram](image-url)
network was kept as simple as possible. (Larger networks consisting of, for example, 50 or 100 nodes gave equivalent simulation results.) There were two different semantic fields, each consisting of a superordinate, two subordinates, and their lemma nodes. This configuration realized all the hypernymy (superordinate → subordinate), hyponymy (subordinate → superordinate), and cohyponymy (subordinate → subordinate) relationships needed. There was an IS-A link (and vice versa a HAS-MEMBER link) between a subordinate and superordinate, and an EXCLUDES link between two mutually exclusive subordinates within a semantic field (cf. Collins & Loftus, 1975).

The presentation of a picture and a word was simulated by adding external input of size $exit$, representing the output of the perceptual stages, to the corresponding concept node and lemma node in the network. For example, in simulating picture naming with a word distractor, the picture input was assigned to DOG(X), and the distractor-word input was assigned to the lemma node of either $fish$ (REL) or $tree$ (UNR). Signalling activation of size $exit$ (enhancing the activation level of the to-be-verbalized concept) was given as soon as the target-source tag arrived at the target concept (e.g., DOG(X) in picture naming, or ANIMAL(X) in picture categorization and word categorization). Signalling activation was given until the selection of a lemma node. An activation tag crossed a link in $tag\_speed$ ms. Distractor input was given to the network for $du$ ms. The SOA was simulated by presenting the distractor input simultaneously with the target input, or at the appropriate number of time steps before or after the onset of the target input. The decay rate of each node in the lexical network was equal to $d$. The spreading rate within the semantic network was $sem\_rate$, that is, all conceptual weights were identical. The spreading rate from concept to lemma node and vice versa was $lem\_rate$. The critical difference for selection was of size $cd$. The simulations were run using time steps $\Delta t$ of 25 ms. (Steps of, for example, 5 or 1 ms gave equivalent simulation results.) For details of the computer simulations, I refer to Roelofs (in preparation).

The values of the seven model parameters described above (used in all simulations reported in this paper) were obtained by maximizing the fit between a restricted number of predictions of the model and corresponding findings in the literature. For the parameter estimations, the data obtained by Glaser and D ü n gelhoff (1984) were taken, because these data embody several of the most important findings on the time course of picture–word interference (cf. Cohen, Dunbar, & McClelland, 1990; MacLeod, 1991; Phaf, Van der Heijden, & Hudson, 1990; Rayner & Springer, 1986). In particular, the estimates were obtained by minimizing the deviation between the predicted and empirically obtained semantic effects (REL minus UNR) for each SOA (ranging from $-400$ to $+400$ in steps of 100 ms) for three tasks: picture naming with word distractor, picture categorization with word distractor, and word categorization with picture distractor. The fit was maximized for the tasks simultaneously, employing the well-known optimiza-
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The parameter values thus obtained were the following:

\[
\begin{align*}
tag\_speed & \quad 25 \text{ [ms per link]} \\
sem\_rate & \quad 0.0101 \text{ [proportion per ms]} \\
lem\_rate & \quad 0.0074 \text{ [proportion per ms]} \\
d & \quad 0.0240 \text{ [proportion per ms]} \\
exin & \quad 0.1965 \text{ [activation unit per ms]} \\
du\_{\text{pnam}} & \quad 75 \text{ [ms]} \quad du\_{\text{pcat}} \quad 200 \text{ [ms]} \quad du\_{\text{wcat}} \quad 125 \text{ [ms]} \\
cd\_{\text{pnam}} & \quad 3.6 \text{ [activation unit]} \quad cd\_{\text{pcat}} \quad 3.2 \text{ [activation unit]} \quad cd\_{\text{wcat}} \quad 3.0 \text{ [activation unit]}
\end{align*}
\]

where \(du\_{pnam}\), \(du\_{pcat}\), and \(du\_{wcat}\) are the distractor durations, and \(cd\_{pnam}\), \(cd\_{pcat}\), and \(cd\_{wcat}\) the critical differences for picture naming, picture categorization, and word categorization, respectively. So, five parameters were kept constant across the tasks, while two parameters were allowed to vary. The \(du\) and \(cd\) were treated as free parameters for the purpose of fine-tuning only. Although the parameter values play a role in the quantitative fit between model data and real data, the explanations of the empirical findings do not depend on them. These findings will be accounted for in structural terms, such as the number of links to be traversed, the presence of response-set flags, and so forth.

To evaluate the fit between the simulated data and the real data (those of Glaser & Düngelhoff, 1984), a \(\chi^2\) statistic was computed. (All statistics for fits reported in this paper are corrected for the number of estimated parameters.) Except for two data-points (to be discussed below), there was no statistical difference between model and data (\(\chi^2\) with \(df = 14\) was 23.4, \(p > .05\)). So, as far as the similarity in SOA functions is concerned, no real reason exists to reject the model.

3.1.1. Picture naming with word distractor

Basic findings. The effect on naming a pictured object (e.g., saying dog to a dog) of the presentation of distractor words (e.g., fish or tree) that are the name of other pictures in the experiment is to increase naming latencies. This increase is greater when the distractor word is semantically related to the picture name (fish) than when it is unrelated (tree): a semantic inhibition effect. Semantic inhibition is observed when the distractor is displayed between 100 ms before and 100 ms after picture onset. Figure 5 shows the amount of inhibition caused by a semantically related distractor compared to an unrelated one as a function of SOA. The empirical data are from Glaser and Düngelhoff (1984, Experiment 1; cf. Guttentag & Haith, 1978, for SOA = 0). Depicted (here and in all figures below) is the mean retrieval time with related distractors, REL, minus the mean retrieval time
with unrelated distractors, UNR. Thus, negative values indicate semantic facilitation, and positive values indicate semantic inhibition.

The theory explains the semantic inhibition as follows. The inhibition is the outcome of a trade-off between the priming of the distractor lemma node by the picture and the priming of the target lemma node by the distractor word. In the unrelated condition, the distractor word will activate its lemma node but not the target lemma node, and the picture will activate the target lemma node but not the distractor lemma node. In the related condition, however, the distractor word will activate its lemma node and also the target lemma node, and the picture will activate the target lemma node and also the distractor lemma node. Because the path from picture to distractor lemma node (DOG(X) → FISH(X) → fish) is shorter than from distractor word to target lemma node (fish → FISH(X) → DOG(X) → dog), the picture will prime the distractor lemma node more than the distractor word will prime the target lemma node (see Figure 4). Furthermore, the target concept (i.e., DOG(X)) gets signalling activation, in addition to the picture input, making it a stronger source of activation than the distractor word. As a result, semantic inhibition will occur.

**Picture distractor.** According to the above explanation, similar SOA functions should occur if, instead of a distractor word, a picture distractor is given. However, now the signalling activation will be the only factor in the trade-off; the paths from distractor picture to target lemma node and from target picture to distractor lemma node will be of the same length (e.g., FISH(X) → DOG(X) → dog and DOG(X) → FISH(X) → fish, respectively). Glaser and
Glaser (1989, Experiment 6) observed similar SOA functions for picture distractors.\(^5\)

I will now show how the theory deals with findings that are considered to be problematic for network accounts of picture-word interference (Lupker, 1979, Experiments 1–3, utilizing SOA = 0).

**Same-category associations.** Lupker obtained a similar interference effect from same-category distractors that were bidirectional associates or non-associates of the name of the picture (e.g., from respectively *foot* and *ankle* printed in a pictured hand). The associative relatedness of category members is often seen in terms of the strength of the connection between their concept nodes (but see Levelt, 1989), where the connection between associated members is assumed to be stronger than between non-associated ones (cf. Collins & Loftus, 1975). In the simulation, increasing the bidirectional connection strength for associates from \(1.0 \times \text{sem}_\text{rate}\) to, for instance, \(3.0 \times \text{sem}_\text{rate}\) resulted in similar effects for associates (*foot*) and non-associates (*ankle*) at SOA = 0, complying with the results obtained by Lupker. Increasing the connection strength in both directions leaves the path from picture to distractor lemma node and from distractor word to target lemma node virtually intact.

**Different-category associations.** Lupker also obtained no difference in interference effect between different-category distractors that were associates or non-associates of the picture's name (e.g., respectively *cheese* and *hand* printed in a pictured mouse). An associative relationship between words from different semantic fields may correspond to a strong labelled (i.e., a conceptually mediated) or unlabelled link between their concept nodes. In Lupker's experiment, the connections were probably labelled, because they concerned links between two semantic fields connected by the fact that a concept in one field specified a property of a concept in the other field (e.g., a *mouse* likes *cheese*). Simulation of Lupker's experiment (with a connection strength of, for example, \(3.0 \times \text{sem}_\text{rate}\) for the associates) showed no difference between the associates (*cheese*) and non-associates (*hand*) at SOA = 0, just as Lupker observed.

**Typicality.** Finally, Lupker observed no difference in effect between distractors denoting typical category members and distractors denoting atypical ones (e.g., respectively distractor *arm* versus *lip* printed in a pictured foot). Typicality is often seen in terms of the connection strength between subordinates and superordi-

---

\(^5\)In the experiment, subjects were instructed to name either the first or the second picture presented. Correspondingly, in the theory, the relevant intersection in determining the target lemma node involves either the first or the second picture tag.
nates, where typical subordinates have a stronger connection to the superordinate than atypical ones (cf. Collins & Loftus, 1975). In the simulation, reducing the connection strength between subordinate and superordinate from $1.0 \times \text{sem\_rate}$ to, for instance, $0.0001 \times \text{sem\_rate}$ for an atypical member, resulted in no difference between distractors denoting typical (\textit{arm}) and distractors denoting atypical category members (\textit{lip}) at SOA = 0, just as Lupker found. Decreasing the connection strength between a subordinate and its superordinate leaves the path from picture to distractor lemma node and from distractor word to target lemma node intact.

In summary, although varying the strength of connections in the network will affect the amount of activation that is sent along a link (and consequently, might explain effects of associative relatedness and typicality on the search of semantic memory, as proposed, for example, by Collins & Loftus, 1975), such a manipulation does not need to result in differences between \textit{distractors} in a picture–word interference experiment.

3.1.2. Picture categorization with word distractor

\textit{Basic findings}. When subjects have to name pictured objects using a hypernym (and the hypernyms of the distractors are part of the response set), for instance, they have to say \textit{animal} instead of \textit{dog} to a pictured dog, one obtains semantic facilitation at negative SOAs. A related distractor word (\textit{dog} or \textit{fish}) will reduce naming latencies compared to an unrelated distractor word (\textit{tree}). Figure 6 shows the amount of facilitation caused by a semantically related distractor word relative to an unrelated one as a function of SOA. The empirical data are again from

![Figure 6](image_url)

**Figure 6.** Mean latency difference (in ms) between REL and UNR per SOA: real and simulated data (real data are from Glaser & Dünghoff, 1984, Experiment 2). A negative difference denotes semantic facilitation.

As can be seen, the model overestimates the amount of facilitation at SOA = –200. (Decreasing, for example, the distractor duration $du$ from 200 ms to 125 ms, reduces the amount of facilitation at SOA = –200 by half, but also diminishes the facilitation at the SOAs of –400 and –300.) Importantly, however, the model displays an increase in facilitation for the negative SOAs: a characteristic of the real data.

The theory explains the semantic facilitation as follows. In a categorization task, the lemma nodes of the hypernyms (e.g., animal, plant) will receive a response-set flag. If the distractor is a related hyponym (fish or dog in a pictured dog), the lemma node of the target hyponym (animal) will be primed by the distractor word via the conceptual network. However, when the distractor word is an unrelated hyponym (e.g., tree), the wrong hypernym node will be primed, in particular, the lemma node of the hypernym of the distractor word (plant), and not the lemma node of the hypernym of the name of the picture (animal). Therefore, one will observe facilitation for semantically related distractors compared to unrelated ones.

**Picture distractor.** Similar SOA functions are predicted if instead of a distractor word a picture distractor is given (e.g., a pictured fish or dog, REL; or tree, UNR). However, now distractors identical to the target (e.g., a picture of a dog repeated; once as distractor and once as target) should lead to more facilitation than distractors that depict other semantically related objects (e.g., a pictured fish as distractor for a pictured dog), due to priming at the object-form perception stage (see Figures 1 and 3). This is precisely what Glaser and Glaser (1989, Experiment 6) observed (cf. Flores D'Arcais & Schreuder, 1987).

**Comparison of picture naming and picture categorization.** According to the theory, picture categorization will take longer than picture naming, due to the difference in path length. In picture categorization, the target-source tag has to cross two links (e.g., $\text{DOG}(X) \rightarrow \text{ANIMAL}(X) \rightarrow \text{animal}$), whereas in picture naming it has to cross only a single link (DOG($X$) $\rightarrow$ dog). This corresponds to what is observed empirically (e.g., Glaser & Düngelhoff, 1984; Glaser & Glaser, 1989; Irwin & Lupker, 1983; Jolicoeur et al., 1984; Smith & Magee, 1980).

### 3.1.3. Word categorization with picture distractor

**Basic findings.** When subjects have to produce the hypernym of words printed in a picture (and hypernyms of the names of the distractor pictures are part of the response set), for instance, they have to say animal to the word dog printed in a picture of a dog or fish (related distractor, REL), or tree (unrelated distractor,
UNR), one obtains a great amount of semantic facilitation up to an SOA of +200 ms. A related distractor (picture of a dog or fish) will enormously decrease naming latencies compared to an unrelated distractor (picture of a tree). Figure 7 shows the amount of facilitation caused by a semantically related distractor picture relative to an unrelated one as a function of SOA. The empirical data are from Glaser and Düngehoff (1984, Experiment 2).

As can be seen, the model underestimates the amount of facilitation at SOA = +200. Importantly, however, the model captures the main characteristics of the real data.

The semantic facilitation effect in word categorization can be explained in the same way as the same effect in picture categorization. However, we must also explain why the facilitation for word categorization is greater than for picture categorization. According to the theory, there are two reasons for this difference. First, picture distractors have more direct access (a shorter path) to the lemma nodes of the hypernyms (both the wrong one in the unrelated condition and the right one in the related condition) than distractor words. For example, in the unrelated condition, the path for a picture distractor will be

\[ \text{TREE}(X) \rightarrow \text{PLANT}(X) \rightarrow \text{plant} \] (wrong hypernym via two links),

and the path for a word distractor will be

\[ \text{tree} \rightarrow \text{TREE}(X) \rightarrow \text{PLANT}(X) \rightarrow \text{plant} \] (wrong hypernym via three links).

Therefore, the wrong hypernym will be primed more by a picture distractor during word categorization than by a word distractor during picture categorization. In the related condition, the path for a picture distractor will be

\[ \text{WORD CATEGORIZATION: hypernyms in response set} \]

![Figure 7. Mean latency difference (in ms) between REL and UNR per SOA: real and simulated data (real data are from Glaser & Düngehoff, 1984, Experiment 2). A negative difference denotes semantic facilitation.](image-url)
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FISH(X) → ANIMAL(X) → animal (right hypernym via two links),
and the path for a word distractor will be

fish → FISH(X) → ANIMAL(X) → animal (right hypernym via three links).

Therefore, the right hypernym will be primed more by a picture distractor during word categorization than by a word distractor during picture categorization. Consequently, the difference between REL and UNR will be larger for word categorization than for picture categorization. Second, the picture targets will activate the target lemma node in picture categorization more than the word targets will activate the target lemma node in word categorization. This is also due to the difference in path lengths. For example, the target path for picture categorization will be DOG(X) → ANIMAL(X) → animal (two links), and for word categorization dog → DOG(X) → ANIMAL(X) → animal (three links). Thus, word categorization will benefit more from a related hyponym than picture categorization.

**Word distractor.** Similar SOA functions are again predicted if instead of a picture distractor a word distractor is given. However, now distractors identical to the target (e.g., dog repeated; occurring once as distractor and once as target) should cause more facilitation than other semantically related ones (e.g., fish as distractor for dog), due to priming of input lexemes at the word-form perception stage (see Figures 1 and 3; cf. Rayner & Pollatsek, 1989). This is precisely what Glaser and Glaser (1989, Experiment 6) found.

**Comparison of picture categorization and word categorization.** The theory also predicts that word categorization will take longer than picture categorization, due to the difference in path length. In word categorization, the target-source tag has to cross three links (e.g., dog → DOG(X) → ANIMAL(X) → animal), whereas in picture categorization it has to cross only two links (DOG(X) → ANIMAL(X) → animal). When I ran the simulation without distractors, word categorization took, on average, 88 ms longer than picture categorization. In their neutral conditions (distractor xxxxxxx) Glaser and Düngelehoff (1984) and Glaser and Glaser (1989) obtained differences (means across SOAs) of 100 and 95 ms, respectively (cf. Irwin & Lupker, 1983).

**3.1.4. Summary of the major results**

Above, I have shown that the theory can explain: (a) the semantic inhibition at SOA ∈ [−100, +100] by word and picture distractors in picture naming, and the absence of an effect of the distractor's typicality and bidirectional associative relatedness; (b) the semantic facilitation at SOA ∈ [−400, −100] by word and
picture distracters in picture categorization, and the increase of the facilitation by picture repetition; (c) the huge amount of semantic facilitation at SOA ∈ [−400, +200] by word and picture distracters in word categorization, and the increase of the facilitation by word repetition. Furthermore, the theory explains the relative processing times for picture naming, picture categorization, and word categorization.

3.2. Speech errors: Blends, substitutions, and exchanges

In the simulation of a picture-word interference experiment, the right lemma will be selected due to the model's intersection mechanism. Nevertheless, the model allows for retrieval errors such as substitutions (e.g., in naming a pictured dog with the word fish superimposed, a subject might say fish instead of dog). These errors will occur if, for example, due to a lapse of attention, the selection is based on an irrelevant intersection (e.g., involving the word tag in picture naming).

The analysis of slips of the tongue occurring in spontaneous speech has been central in the development of theories of speech production (cf. Dell, 1986; Fromkin, 1971; Garrett, 1975, 1976). For instance, speech errors provide evidence for the distinction between lemma retrieval and word-form encoding. If one assumes that lemma retrieval takes place during syntactic encoding and that the retrieval of morphemes and speech segments takes place during the building of the utterance's sound structure, then one can explain the distributional properties of word and sound exchanges. Examples (taken from Dell, 1986) are writing a mother to my letter and flow snurries (for snow flurries). Word exchanges typically occur between items of the same syntactic category and across phrase boundaries (the lemmas of the nouns letter and mother are linked to each other's phrasal slots), while sound exchanges typically do not respect syntactic category and stay within a phrase (the consonant clusters /fl/ and /sn/ are linked to each other's form slots). The latter also holds for stem exchanges (morpheme errors). For example, in slicely thinned (for thinly sliced, taken from Dell, 1986), the stems of an adjective (thin) and a verb (slice) trade places.

Although a quantitative treatment of lemma retrieval failure in spontaneous speech (e.g., Dell's account of errors in word-form encoding) is not within the scope of the theory at its present level of development, a qualitative account is possible and will be given below. For an extensive treatment of errors in word selection, I refer to Dell (1986), Garrett (1980, 1988), Harley (1984), Levelt (1989), and Stemberger (1985), among others. (For reviews of speech errors see, for example, Cutler, 1982; Fromkin, 1973).

Word blends (e.g., a speaker says it has a pretty nice flaste, fusing flavour and taste, from Stemberger, 1985) typically involve semantically related words of the same syntactic category. Word blends might occur when two lemma nodes are
activated to an equal level, and both get selected and encoded as one word form. That is, they may arise when the selection criterion in spontaneous speech (i.e., select the highest activated lemma node of the appropriate syntactic category) is satisfied simultaneously by two lemma nodes. Blends of semantically related words may reflect an indecision on the side of the speaker in encoding the message: two concept nodes that constitute alternative ways of conveying the same message are used to retrieve their lemma nodes, but there is only a single syntactic slot to fill. This would explain why these blends mostly involve near-synonyms, and why antonym blends are highly exceptional.

**Word substitutions** (e.g., a speaker says *don't burn your toes*, but meant to say *fingers*, from Fromkin, 1973) mostly involve words with a semantic and/or associative relationship to the intended word, to another word in the utterance under construction, or to a distractor in the environment (i.e., an object, word, or thought). The substituting word is virtually always of the same syntactic category as the intended one. A substitution might occur when, due to priming via a strong conceptual and/or associative link in the lexical network, a lemma node other than the target satisfies the selection criterion (i.e., has become the highest activated lemma node of the appropriate syntactic category), and is selected.

In **word exchanges** (e.g., a speaker says *a wife for his job*, interchanging *job* and *wife*, from Fromkin, 1973) two exchanged words typically lack a semantic and/or associative relationship, suggesting an etiology different from substitutions. The words involved are mostly of the same syntactic category (though not as often as substitutions). Exchanges might occur when two to-be-verbalized concepts in the message simultaneously retrieve their lemma nodes, and the nodes get erroneously linked to each other's syntactic slot.

### 4. Experimental test of predictions

In this section, the theory is tested empirically on a new set of data. The experiment tests a prediction of the theory that already seems to be refuted by the empirical evidence in the literature. The prediction concerns the semantic effect in picture naming of hypernym, hyponym, and cOHYponym distracters *that are not part of the response set*. For instance, a subject has to say *dog* to a pictured dog, where the distractor is the related *hypernym animal*, the related hyponym *dachshund*, or the related cOHYponym *fish* (now not in the response set); or the distractor is the hypernym, hyponym, or cOHYponym of the name of another picture, for instance, *plant, oak, and bush* (picture of a tree). The theory predicts semantic *facilitation* for these distractor words at negative SOAs. When a subject has to name a picture of a dog, and *animal, dachshund, or fish* is superimposed, the distractor will prime the target lemma node (of *dog*), but will not be a competitor itself, because it is not part of the response set. In contrast, when
plant, oak, or bush is in the picture, there will be no priming of the lemma node of the target dog, but priming of a competitor lemma node in the response set: the node of tree (the name of another picture). Thus, semantic facilitation is to be expected for hypernyms, hyponyms, and cohyponyms alike. The prediction of semantic facilitation by the theory is non-trivial, because evidence against it already seems to exist: La Heij (1988), Lupker (1979), Schriefers et al. (1990), and others, obtained semantic inhibition for distractor words (i.e., cohyponyms) not in the response set. To anticipate the results of the current experiment: the prediction by the theory will be confirmed. Indeed, semantic facilitation will be found. Moreover, it will be shown—informally and by computer simulation—that the theory can resolve this paradoxical situation.

In the experiment, SOAs of −100, 0, and +100 ms will be used, because semantic inhibition by distractors on picture naming typically occurs at SOAs from −100 ms to +100 ms. Therefore, the prediction of facilitation, by the theory, receives its strongest test at these SOAs. The simulation predicts a semantic facilitation of about 25 ms for SOA = −100, and no effect for SOA = 0 and SOA = +100. To simulate related and unrelated hyponyms of hyponyms (e.g., dachshund and oak), the network used previously (see Figure 4) was expanded by attaching extra concept nodes, DACHSHUND(X) and OAK(X), to DOG(X) and TREE(X), and extra lemma nodes, for dachshund and oak, to DACHSHUND(X) and OAK(X), respectively.

4.1. Method

Subjects. Eighteen native speakers of Dutch, from the subject pool of the Max-Planck-Institut für Psycholinguistik (Nijmegen), served as subjects in the experiment. They received Dfl. 8.50 for their participation.

Materials. Nine highly familiar objects were used as target items: dog, tree, car, knife, house, apple, chair, hammer, and coat. The pictures of the objects satisfied the following criteria: (1) subjects spontaneously named the pictures with the intended names, for example, hond (dog), boom (tree), auto (car), and so forth; (2) subjects considered the intended hypernym and hyponym of the target name to be appropriate labels for the pictures; for example, voertuig (vehicle) and jeep (jeep) were considered to be plausible names for the depicted car, but the intended cohyponym tractor (tractor) not; (3) the hypernym, hyponym, and cohyponym consisted of a single word; for example, moker (sledge) would be appropriate, but Engelse sleutel (adjustable spanner) not; (4) the hypernym, hyponym, and cohyponym did not contain the name of the target word as a proper part; for example, keukenstoel (kitchen chair) as a hyponym of stoel (chair) would not be suitable, whereas troon (throne) would; (5) the hypernym, hyponym, and cohyponym did not share initial letter(s) with the target word to prevent orthographic priming (cf. Rayner & Springer, 1986).
The nine pictures were selected from a set of 19 candidate pictures. These 19 pictures were presented to ten subjects (who did not participate in the actual experiment) with the instruction to name the depicted object. If subjects spontaneously gave the intended name, they were asked whether the hypernym, hyponym, and cohyponym were also suitable names for the pictured object. For nine selected pictures, all subjects spontaneously gave the correct name, and agreed on the appropriateness of the hypernym and hyponym, and on the inappropriateness of the cohyponym. Table 1 lists the experimental stimuli, for each of the nine target picture names, the distractor hypernym (SUPER/REL),

Table 1. **Materials. See text for explanation**

<table>
<thead>
<tr>
<th>Distractor</th>
<th>Picture name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUPER/REL</td>
<td>auto: voertuig</td>
</tr>
<tr>
<td>COORD/REL</td>
<td>tractor: dier</td>
</tr>
<tr>
<td>SUBOR/REL</td>
<td>jeep: tekkelen</td>
</tr>
<tr>
<td>SUPER/UNR</td>
<td>plant: wapen</td>
</tr>
<tr>
<td>COORD/UNR</td>
<td>flat: banaan</td>
</tr>
<tr>
<td>SUBOR/UNR</td>
<td>doll: troon</td>
</tr>
<tr>
<td>CONTR</td>
<td>x xxxxxx</td>
</tr>
<tr>
<td>SUPER/REL</td>
<td>appel: fruit</td>
</tr>
<tr>
<td>COORD/REL</td>
<td>banaan: kast</td>
</tr>
<tr>
<td>SUBOR/REL</td>
<td>goudreinet: troon</td>
</tr>
<tr>
<td>SUPER/UNR</td>
<td>gereedschap: kleding</td>
</tr>
<tr>
<td>COORD/UNR</td>
<td>tractor: poes</td>
</tr>
<tr>
<td>SUBOR/UNR</td>
<td>colbert: jeep</td>
</tr>
<tr>
<td>CONTR</td>
<td>x xxxxxx</td>
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<table>
<thead>
<tr>
<th>Distractor</th>
<th>Picture name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUPER/REL</td>
<td>dog: animal</td>
</tr>
<tr>
<td>COORD/REL</td>
<td>pass: dachshund</td>
</tr>
<tr>
<td>SUBOR/REL</td>
<td>plant: banana</td>
</tr>
<tr>
<td>SUPER/UNR</td>
<td>flat: throne</td>
</tr>
<tr>
<td>COORD/UNR</td>
<td>dagger: xxxxxx</td>
</tr>
<tr>
<td>CONTR</td>
<td>xxxxxx</td>
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<th>Distractor</th>
<th>Picture name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUPER/REL</td>
<td>apple: furniture</td>
</tr>
<tr>
<td>COORD/REL</td>
<td>banana: cabinet</td>
</tr>
<tr>
<td>SUBOR/REL</td>
<td>golden rennet: throne</td>
</tr>
<tr>
<td>SUPER/UNR</td>
<td>tool: clothes</td>
</tr>
<tr>
<td>COORD/UNR</td>
<td>tractor: jeep</td>
</tr>
<tr>
<td>SUBOR/UNR</td>
<td>jacket: xxxxxx</td>
</tr>
<tr>
<td>CONTR</td>
<td>xxxxxx</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Distractor</th>
<th>Picture name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUPER/REL</td>
<td>knife: weapon</td>
</tr>
<tr>
<td>COORD/REL</td>
<td>house: building</td>
</tr>
<tr>
<td>SUBOR/REL</td>
<td>golden rennet: cabinet</td>
</tr>
<tr>
<td>SUPER/UNR</td>
<td>tool: sledge</td>
</tr>
<tr>
<td>COORD/UNR</td>
<td>tractor: dachshund</td>
</tr>
<tr>
<td>SUBOR/UNR</td>
<td>jacket: xxxxxx</td>
</tr>
<tr>
<td>CONTR</td>
<td>xxxxxx</td>
</tr>
</tbody>
</table>

**English translation**

<table>
<thead>
<tr>
<th>Distractor</th>
<th>Picture name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUPER/REL</td>
<td>car: animal</td>
</tr>
<tr>
<td>COORD/REL</td>
<td>pass: dachshund</td>
</tr>
<tr>
<td>SUBOR/REL</td>
<td>plant: banana</td>
</tr>
<tr>
<td>SUPER/UNR</td>
<td>flat: throne</td>
</tr>
<tr>
<td>COORD/UNR</td>
<td>dagger: xxxxxx</td>
</tr>
<tr>
<td>CONTR</td>
<td>xxxxxx</td>
</tr>
<tr>
<td>SUPER/REL</td>
<td>fruit: furniture</td>
</tr>
<tr>
<td>COORD/REL</td>
<td>banana: cabinet</td>
</tr>
<tr>
<td>SUBOR/REL</td>
<td>golden rennet: throne</td>
</tr>
<tr>
<td>SUPER/UNR</td>
<td>tool: clothes</td>
</tr>
<tr>
<td>COORD/UNR</td>
<td>tractor: jeep</td>
</tr>
<tr>
<td>SUBOR/UNR</td>
<td>jacket: xxxxxx</td>
</tr>
<tr>
<td>CONTR</td>
<td>xxxxxx</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distractor</th>
<th>Picture name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUPER/REL</td>
<td>knife: weapon</td>
</tr>
<tr>
<td>COORD/REL</td>
<td>house: building</td>
</tr>
<tr>
<td>SUBOR/REL</td>
<td>golden rennet: cabinet</td>
</tr>
<tr>
<td>SUPER/UNR</td>
<td>tool: sledge</td>
</tr>
<tr>
<td>COORD/UNR</td>
<td>tractor: dachshund</td>
</tr>
<tr>
<td>SUBOR/UNR</td>
<td>jacket: xxxxxx</td>
</tr>
<tr>
<td>CONTR</td>
<td>xxxxxx</td>
</tr>
</tbody>
</table>
hyponym (SUBOR/REL), and cohyponym (COORD/REL). The labels will be explained below.

**Design.** There were two crossed within-subjects factors. The first factor was SOA with three levels: the distractor was exposed before picture onset by 100 ms, simultaneously with the picture, or after picture onset by 100 ms. The second factor was distractor type with seven levels: SUPER/REL (name of a related superordinate or hypernym), SUBOR/REL (name of a related subordinate or hyponym), COORD/REL (name of a related coordinate or cohyponym), SUPER/UNR (name of an unrelated superordinate), SUBOR/UNR (name of an unrelated subordinate), COORD/UNR (name of an unrelated coordinate), and CONTROL. In the SUPER/REL, SUBOR/REL, and COORD/REL condition a picture was combined with, respectively, its hypernym, hyponym, or cohyponym. In the SUPER/UNR, SUBOR/UNR, and COORD/UNR condition the distractor was, respectively, the hypernym, hyponym, or cohyponym of the name of one of the other pictures. In the CONTROL condition the distractor consisted of a row of six x’s (mean length of the distractor words). By taking the difference between the means of SUPER/REL and SUPER/UNR, SUBOR/REL and SUBOR/UNR, and COORD/REL and COORD/UNR one gets the semantic effect of, respectively, hypernymy, hyponymy, and cohyponymy. By taking difference scores, each distractor word serves as its own control. The CONTROL condition was included as a safeguard. If no difference between REL and UNR for all levels of abstraction and all SOAs would be found (in several SOA = 0 pilots conducted in preparation of this experiment, this was indeed the case), the CONTROL condition could be used as a check for whether or not this absence is due to an ability of the subjects to ignore the distractors. Normally, for the SOAs involved, presenting a word (either REL or UNR) as a distractor results in slower response latencies than presenting a string of x’s (cf. Glaser & Düngelhoff, 1984).

Three different lists of picture–word stimuli were created (L1, L2, and L3). A list consisted of 63 picture–word combinations (7 distractors each of a different distractor type and 9 pictures) randomly ordered with the following restrictions: no particular picture or word occurred in two consecutive trials; target and distractor name never shared initial phonemes; the distractor in one trial and the target of the next trial were never semantically related, and vice versa, nor were the distractors in two consecutive trials of the same abstraction level (e.g., both subordinates). Within a list, every distractor word appeared once in the REL condition, and once in the UNR condition. Picture–word pairing was constant across lists; for the pairing, see Table 1. The lists (L1, L2, L3) were presented to each subject in constant-SOA blocks (SOA is −100, 0, or +100 ms), each list combined with a different SOA. The assignment of levels of SOA and lists to blocks (first, second, third) was counterbalanced across subjects.

**Apparatus.** The pictures were drawn by hand, then digitized using a Hewlett-Packard scan application, and tidied up with the editing facilities of MS-Paint. The
pictured objects were approximately 15 cm high and 9 cm wide. In the centre of the pictured object a word field was kept free of lines of the drawing to avoid overlap with the distractor word. Distractor words were presented in lower-case letters, which were about 8 mm high and 6 mm wide. The stimuli were displayed on a high-resolution CRT screen (NEC-MULTISYNC). The picture outlines and the words were presented in white on a black background. Naming latencies were measured by means of a voice key. Presentation of the stimuli and registration of naming latencies were controlled by a HERMAC PC-AT computer.

Procedure. All subjects were tested individually in a darkened soundproof booth. They sat about 0.75 m away from the CRT screen. The subjects were told that they would see a series of pictures with words or a series of x’s superimposed, and that their job was to name the pictures as rapidly as possible without making mistakes. Before the experiment, they were shown a booklet with the pictures and the names to be used. Each trial involved the following sequence. An asterisk appeared in the centre of the screen as the ready signal. After a button press by the subject, following an interval of 750 ms, the picture and word were presented at the appropriate SOA. The picture remained on the screen until the subject started speaking, with a maximum presentation duration of 1.5 s. The time between trials was 2.5 s. After each trial the experimenter coded the response for errors. Experimental sessions were recorded on audio tape. This recording was consulted after the experiment when the experimenter was in doubt about whether the response given was correct.

A session involved three constant-SOA blocks of 63 picture–word stimuli each. Between each block there was a short break. Before the experimental session, subjects received a practice session consisting of 28 picture–word stimuli (7 distractor types and 4 pictures) presented with SOA = 0. The structure of the practice block was the same as the experimental blocks. The practice pictures and distractors were not repeated in the experimental session, and were not semantically related to any of the experimental stimuli. A complete session lasted approximately half an hour.

4.2. Results and discussion

Excluded from the analysis were (1) responses where a subject gave an incorrect name, made a sound error, repaired, stuttered, or produced mouth clicks (in total 0.94% of all responses, see Table 2 for the error rate per condition), (2) responses where the apparatus malfunctioned, and (3) responses with a latency longer than 1500 ms and latencies deviating more than two standard deviations from a subject’s and item’s mean (5.7% of all responses). The excluded data points were replaced by estimates following Winer (1971). Table 2 lists the mean naming latencies per SOA and distractor type.
Table 2. Mean naming latencies (ms) per SOA and distractor type (n = 162). Between brackets the error rate, and between parentheses the difference between REL and UNR per level of abstraction.

<table>
<thead>
<tr>
<th>SOA</th>
<th>Condition</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-100</td>
<td>CONTROL</td>
<td>588 [1.2]</td>
</tr>
<tr>
<td></td>
<td>SUPER/REL</td>
<td>607 [1.9]</td>
</tr>
<tr>
<td></td>
<td>SUPER/UNR</td>
<td>615 [0.0]</td>
</tr>
<tr>
<td></td>
<td>COORD/REL</td>
<td>607 [1.2]</td>
</tr>
<tr>
<td></td>
<td>COORD/UNR</td>
<td>628 [1.2]</td>
</tr>
<tr>
<td></td>
<td>SUBOR/REL</td>
<td>613 [1.2]</td>
</tr>
<tr>
<td></td>
<td>SUBOR/UNR</td>
<td>642 [1.9]</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>(-8)</td>
</tr>
<tr>
<td></td>
<td>(mean -19)</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>CONTROL</td>
<td>582 [0.0]</td>
</tr>
<tr>
<td></td>
<td>SUPER/REL</td>
<td>626 [1.2]</td>
</tr>
<tr>
<td></td>
<td>SUPER/UNR</td>
<td>625 [1.9]</td>
</tr>
<tr>
<td></td>
<td>COORD/REL</td>
<td>645 [0.0]</td>
</tr>
<tr>
<td></td>
<td>COORD/UNR</td>
<td>636 [0.0]</td>
</tr>
<tr>
<td></td>
<td>SUBOR/REL</td>
<td>639 [0.0]</td>
</tr>
<tr>
<td></td>
<td>SUBOR/UNR</td>
<td>634 [0.0]</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>(+1)</td>
</tr>
<tr>
<td></td>
<td>(mean +5)</td>
<td></td>
</tr>
<tr>
<td>+100</td>
<td>CONTROL</td>
<td>590 [0.0]</td>
</tr>
<tr>
<td></td>
<td>SUPER/REL</td>
<td>626 [0.6]</td>
</tr>
<tr>
<td></td>
<td>SUPER/UNR</td>
<td>629 [1.9]</td>
</tr>
<tr>
<td></td>
<td>COORD/REL</td>
<td>634 [1.2]</td>
</tr>
<tr>
<td></td>
<td>COORD/UNR</td>
<td>628 [0.6]</td>
</tr>
<tr>
<td></td>
<td>SUBOR/REL</td>
<td>630 [1.2]</td>
</tr>
<tr>
<td></td>
<td>SUBOR/UNR</td>
<td>640 [2.5]</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>(-3)</td>
</tr>
<tr>
<td></td>
<td>(mean -2)</td>
<td></td>
</tr>
</tbody>
</table>

For each SOA the difference between the REL and UNR condition for each level of abstraction (SUPER, SUBOR, COORD) was computed. The mean differences are given in parentheses in Table 2. The difference scores, indicating respectively the semantic effect of hypernymy, hyponymy, and cohyponymy, were submitted to a by-subjects and by-items ANOVA, with SOA and level of abstraction as fixed factors.

The ANOVA on the difference scores yielded a main effect of SOA ($F_1(2,34) = 6.01, MSe = 1312, p < .006; F_2(2,16) = 8.16, MSe = 481, p < .003$); pairwise comparisons revealed that the difference between REL and UNR at SOA = -100 was significantly greater than the difference at SOA = 0 and at SOA = +100 (by-subjects, respectively $t(17) = 3.46, p < .005, t(17) = 1.89, p < .05$; by-items, respectively $t(8) = 4.04, p < .005, t(8) = 2.84, p < .02$). The difference between REL and UNR at SOAs 0 and +100 did not differ significantly (by subjects, $t(17) = 1.56, p > .1$; by items $t(8) = 1.20, p > .2$). The data therefore show an SOA-dependent semantic effect.

There was no main effect of level of abstraction ($F_1(2,34) = 0.78, MSe = 1520, p > .4; F_2(2,16) = 0.68, MSe = 1043, p > .5$). Furthermore, SOA and level of abstraction did not interact ($F_1(4,68) = 1.09, MSe = 1342, p > .3; F_2(4,32) = 0.69, MSe = 687, p > .6$), showing that the semantic effect did not differ for hypernyms, hyponyms, and cohyponyms. I will therefore treat the levels of abstraction as equivalent as far as their semantic effect is concerned. Figure 8 depicts for each
SOA the mean difference between REL and UNR collapsed over levels of abstraction (SUPER, SUBOR, and COORD).

The data show a semantic facilitation at the negative SOA, as was predicted by the theory. Figure 8 shows that the quantitative predictions by the computer model are also met (means for the SOA of −100, 0, and +100, respectively, −25, −1, and 0 ms). (The size of the critical difference, cd, was estimated anew, keeping the rest of the parameters fixed. A critical difference of 1.1 appeared to minimize the deviation.) The $\chi^2$ measure of fit between simulated and real data was equal to 3.1 ($df = 2$, $p > .2$, n.s.). This means that the predictions of the simulation are statistically not different from the real data.

An apparent contradiction. La Heij (1986) and Lupker (1979), among others, observed semantic inhibition at SOA = 0 with cohyponym distracters that were not part of the response set (their studies did not include hypernyms and hyponyms). Although in the experiment reported above, the responses for the cohyponyms in the related condition differed from those in the unrelated condition by 9 ms, this difference was statistically not reliable (by subjects, $t(17) = 0.99$, $MS_e = 697$, $p > .1$; by items $t(8) = 1.44$, $MS_e = 165$, $p > .05$). These studies therefore seem to be in conflict.

How might this conflict be resolved? First, consider the experiments of La Heij. In contrast to the current study with only one response-set member per semantic field, his study had three response-set members from one semantic domain, for example, piano, trumpet, guitar; or hammer, pincers, chisel (cf. Cohen et al., 1990). So, although a number of distractor words (e.g., violin or drill) were not part of the response set, these words could nevertheless prime a
competitor lemma node. For instance, in naming a pictured piano, the lemma nodes of *trumpet* and *guitar* would be primed by distractor *violin* in the REL condition; and the lemma nodes of *hammer, pincer, and chisel* would be primed by distractor *drill* in the UNR condition. Therefore, La Heij’s results can be explained in the same way as the findings of Glaser and Dündelhoff (1984). In the related condition the picture and the distractor word activate the same response-set competitors of the picture name, whereas in the unrelated condition different competitors are activated by the picture and the distractor word. The only difference between the studies is that in the Glaser and Dündelhoff experiment the distracters were actually part of the response set, whereas in La Heij’s experiments they were cohyponyms of response-set members. This also explains why La Heij did not find an interaction between semantic relatedness and response-set membership; that is, why the semantic effect was the same for distractors that were in the response set (e.g., *trumpet* vs. *hammer*) and distractors that were not in the response set (e.g., *violin* vs. *drill*). According to the theory, the distractors that were not part of the response set nevertheless behaved *indirectly* as response-set members, by activating response-set competitors of the picture name, in REL as well as in UNR.

Second, distractors that are not part of the response set may cause semantic inhibition if the retrieval mechanism is more sensitive to activation in the lexical environment of the target lemma (i.e., nodes that are close to a relevant intersection) than to activation outside that environment. According to the theory, the activation of the lemmas from the same semantic field as the target would receive a heavier weight in the Luce ratio than the activation of the lemmas from a different semantic field. The weighting *is the same* for the REL condition and the UNR condition. However, the effect on the lemma retrieval latency will be different for the semantically related and unrelated distractors. A semantically related distractor will activate the target but also the target’s neighbours (including its own lemma node), thereby increasing the denominator of the Luce ratio, and decreasing the probability that the target node will be actually selected. For an unrelated distractor this will not be the case. Once again there is a trade-off between the priming of the target and the priming of competitors, now via the Luce ratio.

The computer simulation shows that increasing the sensitivity to activation in the lexical environment of the target lemma indeed results in semantic inhibition (as observed by Lupker, 1979, and Schriefers et al., 1990), instead of a null effect (as in the simulation and real data of the experiment reported above). Multiplying the activation values of neighbour lemma nodes by 2, 3, or 4 results in a semantic inhibition at SOA = 0 of about 15, 25, and 35 ms, respectively. At the earlier SOAs there may still be facilitation, as in the experiment reported above; at later SOAs, there may again be a null effect, similar to the experiment reported above and to what Schriefers et al. observed. Thus, variation on an attention parameter may underlie the differences between these studies.
5. Summary and conclusions

I have described a spreading-activation theory designed to explain certain aspects of lemma retrieval in speaking. In the theory the mental lexicon is conceived of as a network with concept, lemma, and lexeme nodes and labelled links, with each lexical concept represented as an independent node. A lemma is retrieved by enhancing the activation level of the node of the to-be-verbalized concept. The activation then spreads to the lemma level, where the highest activated lemma node is selected. For lemma retrieval in the picture-word interference paradigm, three extra assumptions were made. First, source tags are transmitted by the external sources of activation (picture and word). Second, response-set flags indicate which lemmas are permitted responses in an experiment. Third, the target lemma (the lemma searched for) is determined by the intersection of the tag from the target source (e.g., the picture in picture naming) and one of the response-set flags.

The theory has much in common with earlier proposals by Collins and Loftus (1975), Dell (1986), and others, but there are also some important differences. In contrast to Dell (1986), Dell and Reich (1981), and Stemberger (1985), a lexical concept is represented by an independent node in the network. This characteristic allows the retrieval mechanism to cope with hypernymy and word-to-phrase synonymy. In contrast to Collins and Loftus (1975) and many others (e.g., Glaser & Glaser, 1989; Nelson, Reed, & McEvoy, 1977; Potter, 1979; Sc mour, 1979; Smith & Magee, 1980; Snodgrass, 1984; Theios & Amrhein, 1989), the theory postulates no direct connection between lexical-concept nodes and word-form nodes. These nodes are indirectly connected via a lemma node. Word retrieval therefore involves both a stage of lemma retrieval and a stage of word-form encoding. This characteristic of the theory is consistent with the findings of a variety of experimental paradigms, tip-of-the-tongue findings, speech-error data, and data on aphasia (see Introduction and section 3.2).

I have shown that the theory can account for many empirical findings on the time course of object naming, object categorization, and word categorization. Some novel and non-trivial predictions were also tested and confirmed in a new experiment. Future experiments could test the theory further by employing new paradigms, for example, paradigms requiring syntactic encoding (cf. Bock, 1986; Bock & Warren, 1985; Kelly, Bock, & Keil, 1986; Kempen & Huijbers, 1983; Levelt & Maassen, 1981; Levelt, 1989). It may also be possible to test whether the theory's predictions hold for words other than nouns, such as verbs and adjectives.

The theoretical assumptions I have made are very simple, and yet are sufficient to handle hypernymy and word-to-phrase synonymy, and to account for many empirical findings on conceptually driven lemma retrieval. The challenge is now for theorists to develop a decompositional theory that solves the retrieval problems and accounts for the data in a more parsimonious way.
Appendix: Derivation of the expected retrieval latency $E(T)$

Let $T$ denote time, let $s$ be the $s$th time step ($s = 1, 2, \ldots$), and $\Delta t$ the duration of a time step (in ms)

Definitions:

$$f(s) = p(\text{selection at } s)$$
$$h(s) = p(\text{selection at } s \mid \neg \exists u: (u < s \land \text{selection at } u))$$

respectively, the probability mass function and the hazard rate function.

Derivation of $f(s)$ from $h(s)$:

$$h(s) = p(\text{selection at } s \mid \neg \exists u: (u < s \land \text{selection at } u))$$

$$= \frac{p((\text{selection at } s) \land (\neg \exists u: (u < s \land \text{selection at } u)))}{p(\neg \exists u: (u < s \land \text{selection at } u))}$$

$$= \frac{p(\text{selection at } s)}{p(\neg \exists u: (u < s \land \text{selection at } u))}$$

$$= f(s) \prod_{i=0}^{s-1} [1 - h(j)]$$

$$\Rightarrow f(s) = h(s) \prod_{j=0}^{s-1} [1 - h(j)]$$

where $h(0) = 0$.

For the expectation of $T$ holds:

$$E(T) = \sum_{s=1}^{\infty} f(s)s \Delta t$$

$$= \sum_{s=1}^{\infty} h(s) \left( \prod_{j=0}^{s-1} [1 - h(j)] \right) s \Delta t$$

References


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