Simulations with a Connectionist Model for Implicit and Explicit Memory Tasks

R. Hans Phaf and **Michiel S. A. van Immerzeel**
Psychonomics Department, Faculty of Psychology, University of Amsterdam,
Roetersstraat 15, 1018 WB Amsterdam, The Netherlands
`pn_phaf@macmail.psy.uva.nl`

Abstract

A connectionist model incorporating activation and elaboration learning was investigated in five simulations of dissociation effects between implicit and explicit memory tasks. The first two simulations concerned the word frequency effect, revealing a high-frequency advantage in free recall and a low-frequency advantage in word completion. The third and fourth simulations were of the interference effect, which appeared to depend upon the amount of overlap between experimental material and intervening material. The last simulation addressed the focused vs. divided attention dissociation effect. Free recall performance was primarily affected by divided attention, but under conditions of high load word completion performance was also reduced. It is argued that a full model will probably not only implement activation/elaboration learning, but will also incorporate elements of the two other accounts available.

Introduction

Explicit (direct) memory tests, such as free recall, recognition, and cued recall, make a reference to the learning episode, whereas implicit (indirect) memory test, such as word completion and perceptual identification, do not necessarily direct the subject to the fact that memory is being tested. Dissociation effects between these two types of memory testing (see Richardson-Klavehn & Bjork, 1988; Schacter, 1987) indicate that different mechanisms or neural structures may underlie both types of performance. One explanation assumes two separate memory systems that are functionally different (e.g., Tulving & Schacter, 1990). Another explanation assumes different processes in a unitary memory system. Compatibility between processes at storage and testing may, for instance, explain dissociations between explicit and implicit memory performance (e.g., Roediger & Blaxton, 1987). Graf and Mandler (1984), on the other hand, made a distinction between two different learning processes, activation and elaboration learning. The two processes strengthen different components of a distributed memory representation. Activation learning represents a kind of Hebbian learning in which pre-existing associations are strengthened after presentation. An implicit memory task requires the partial or complete reinstatement of a stimulus-representation by using the associations that constitute the representation. Implicit memory performance is enhanced when a prior stimulus presentation has strengthened the pre-existing internal associations. Explicit memory tasks require access to a stimulus-representation via retrieval routes that address newly formed links between the representation and information specific for the learning episode (the 'context'). This kind of test depends upon the formation of new associations (elaboration learning) resulting either from active attentional processing or as an automatic consequence of the novelty of stimulus combinations. Probably elements from these three accounts have to be combined to get a full explanation.

A network model (ELAN: ELaboration and Activation Network) implementing a version of the activation/elaboration account was constructed by Phaf (1994; see also Raccuglia & Wolters, 1996). The simplest version of the model (ELAN-1) is formed by two CALM modules (Categorization And Learning Module; see Murre, Phaf, & Wolters, 1992). A CALM is a competitive learning module that is able to categorize and learn arbitrary input patterns without supervision. In CALM the elaboration process depends on the amount of competition in the module. When a novel pattern is presented there will be much competition, which will be reduced when the pattern becomes well established. Elaboration results in an increased learning rate and an increased amplitude of (uniformly distributed) random activations to representation nodes relative to activation learning. The random activations serve to break symmetry and to solve competition by randomly selecting a node for the new representation. A baseline level of Hebbian type activation learning is always present in CALM, irrespective of the amount of elaboration learning.

One CALM module in the model served to represent words and the other represented environmental contexts in which words may be learned. The word patterns and context patterns were presented through separate input modules. An output module selected single words at a time for output. This simple model already showed results comparable to experimental findings, such as a reversed word frequency effect in word completion relative to free recall. Anterograde amnesia could also be simulated by artificially lesioning the model, so that elaboration learning was eliminated.

A problem with this model was that it was not very well suited to separate strongly correlated patterns. Words are strongly correlated because they have letters and other (e.g., semantic) components in common. Contexts are probably also correlated, because they may have overlapping features. The words in the model, however, only had a weak correlation and the contexts were orthogonal. The model may not be very well suited to deal with more realistic input patterns because the building blocks of the model, the CALM module, only has a limited ability to separate correlated input patterns. This ability is improved in the CALM Map (Phaf, Tijsseling, & Lebert, Submitted), which implements topological self-organization in CALM modules by introducing a (Gaussian) gradient in the lateral inhibition. CALM Maps may improve on Kohonen's self-organizing feature map (Kohonen, 1982), because they are able to internally regulate its learning parameters and activity bubble, which is a natural by-product of the novelty dependent elaboration mechanism. In this study, we examined whether an ELAN-1 model with CALM Maps could perform the same simulations as the old model when more correlated input patterns were presented. A second aim was to simulate more dissociation effects than with the old model.

Architecture of the Model

The core of the new model (see Figure 1) was formed by two CALM Maps with ring topology (see Phaf *et al.*, Submitted), one for representing words and one for representing contexts. Six additional modules figure in the model, five to provide input to the network and one to produce output from the network. Words were presented to the network through four input modules which consisted of 10 input-nodes each. They were linked to the word-module by uni-directional connections from all input-nodes to all R-nodes of the word-module. During learning, input-nodes became associated to a winning bubble (a winning R-node with activated neighborhood) in the word-module (representing the word). The context-input module (6 nodes) was similarly connected to the context-CALM Map. An input pattern in the context-input module represented an environmental context in which words may be presented. The word-CALM Map (25 R-nodes) and the context-CALM Map (9 R-nodes) were linked by bi-directional (but not symmetrical) connections between all R-nodes of both modules. These weights were independently modifiable in both directions.

Retrieval of a word took place in this model along two different routes, by presenting either a context or a word part as a cue. The output module, which can only output one word at a time was coupled to the word-CALM Map. Only after resolution of competition in the CALM Map, the activation of the winning node is passed to the output module, because only then is the veto-node in the output module no longer activated from the CALM Map. Subsequently, the activation of one of the nodes in the output module inhibits (and resets) the activations through veto-nodes in both CALM Maps. After the output activation has decayed, the process of finding a word response starts again. This can repeat itself indefinitely, as long as input activations are provided (for more detailed discussion of ELAN-1 and the output module see Phaf, 1994; Van Immerzeel, 1996; for parameters and weight values see Appendix).

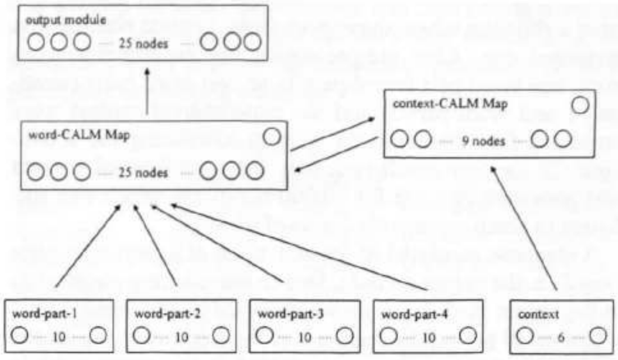

Figure 1: The ELAN-1 model with schematic wiring pattern.

General Description of Simulations

All simulations of experiments with ELAN-1 proceeded in three stages, a pre-experimental learning stage, an experimental learning stage, and an experimental testing stage. According to the activation/elaboration view, implicit memory performance is for a large part caused by the strengthening of existing associations. Therefore, before the simulation of the memory experiments could begin, the 'empty' networks had to be filled with a basic lexicon. This first stage corresponds to pre-experimental learning and simulates the acquisition of knowledge by a subject before taking part in an experiment. Because in CALM Maps the formation of associations is driven by a stochastic process, each presentation of the same series of words in contexts may lead to a different network. These differences may in some way reflect individual variations between real subjects. For every simulation 25 different artificial subjects were created by exposing similar networks to the same stimulus set.

Each of the twenty words had two word parts in common with each of its two neighboring words. The ten word part consisted of two activations of 0.5, whereas the other nodes in the input module had zero activation (e.g., 0.5, 0.5, 0, 0, 0, 0, 0, 0, 0, 0). The input patterns for six contexts similarly consisted of two activations of 0.5 and four others with zero activation (e.g., 0, 0, 0.5, 0.5, 0, 0). Before pre-experimental learning, all learning connections were initialized to 0.5 (maximum 1.0, minimum 0.0). Before every presentation, all activations (but not the weights) were initialized to zero. In order to prevent premature response production, the veto-node in the output module was pre-activated. This can be compared to the pre-response verbal activity which has to be replaced by verbal responses.

In the second stage, a subset of the words (experimental list) learned pre-experimentally was presented under the experimental context. The experimental context pattern (0, 0.5, 0, 0.5, 0, 0.5) formed a balanced combination of all six context patterns from the first stage. A single presentation of a word lasted 5000 iterations (i.e., a cycle of calculating the new activations of all nodes and the new weight values of the modifiable weights). Before presentation of the experimental list, the experimental context was presented 500 times for 25 iterations without word input, resulting in a stable representation for the experimental context. This can be seen as the time spent in the experimental context before presentation of the experimental words.

Both before and after experimental learning the memory for the experimental words was tested either implicitly (a word completion task) or explicitly (a cued recall task or a free recall task). Because all tests were done on copied networks, performance on tests may be treated as a within-subjects factor. In the word completion task only the word-part-1s without context were presented in random order as a cue for 100 iterations. In the cued recall task the experimental context was pre-presented for 100 iterations. This simulated a situation where the experimental context was the first presented cue. After pre-presenting the experimental contexts, one word part (word-part-1) or two word parts (word-part-1 and word-part-3) and the experimental context were presented for 100 iterations without initializing the activations. In the free recall task only the experimental context was presented as a cue for 10,000 iterations, which was sufficient to reach asymptotic levels of recall.

A response consisted of the activation of a particular node (word) in the output module. Due to the resetting mechanism in the output module, many words could be produced during a free recall period. Correctness of the responses was scored against the nodes that were activated in the output module during experimental learning. All results were averaged over 25 artificial subjects. Base rate performance was determined on the same (copied) artificial subjects by counting the production of critical words before experimental presentation.

Word Frequency

It has been hypothesized (e.g., Phaf, 1994; Tulving & Kroll, 1995) that low-frequency (LF) words are more novel and would, therefore, elicit more elaboration learning than high-frequency (HF) words. Intra-item associations may also benefit from such elaboration. LF words could, therefore, also show a larger facilitation in an implicit memory task than HF words. MacLeod and Kampe (1996) and Phaf and Wolters (1996) indeed found a higher word completion performance for LF words than for HF words. The new item-context associations are not affected by this additional elaboration. HF words are, however, assumed to be accessible through a larger range of contexts than LF words. Consequently, HF words have the highest chance of being selected during free recall.

Simulation 1

Procedure. First a lexicon of HF words and LF words had to be created. Ten HF words (word 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20) were presented (for 25 iterations) under four contexts (context 1, 3, 4, and 6) and ten LF words (word 1, 3, 5, 7, 9, 11, 13, 15, 17, and 19) under two other contexts (context 2 and 5). The presentation of all word/context combinations was repeated 200 times in random order, which resulted in 400 presentations of a LF word and 800 presentations of a HF word. In the second stage all artificial subjects were copied for the two frequency conditions, so that word frequency would be a within-subjects manipulation. After pre-presentation of the experimental context, the groups received their word set once in random order under the experimental context.

Results and discussion. Word completion performance (see Table 1) for both LF words as HF words showed facilitation after experimental presentation. The average increase (above base rate) for LF words was higher than for HF words. A similar result was found in the simulation of Phaf (1994). Free recall performance (see Table 1) was somewhat higher for HF words than for LF words. Phaf (1994) found a similar effect, but absolute free recall performance was lower (HF words 0.28, LF words 0.23). LF words benefited more from the higher level of elaboration during learning than HF-words, but this advantage was overridden by the larger access of HF words in free recall.

Although cued recall is supposed to be an explicit memory task, the average increase on both cued recall tasks was higher for LF words than for HF words. The influence of the context-cue is probably less strong than the influence of the word part-cue(s). Performance, therefore, almost completely reflected word completion performance, but cued recall performance appeared to be lower. The context-cue may have interfered with retrieval through the word part-cue by activating other nodes in the (competitive) word-CALM Map. The simulation of cued recall clearly needs to be improved.

	High-frequency words				Low-frequency words			
	WC	FR	CR1	CR2	WC	FR	CR1	CR2
Base rate	0.53	0.00	0.48	0.52	0.26	0.00	0.27	0.24
(sd)	(0.13)	(0.00)	(0.16)	(0.15)	(0.15)	(0.00)	(0.15)	(0.13)
Experiment	0.73	0.70	0.46	0.62	0.68	0.65	0.43	0.60
(sd)	(0.14)	(0.32)	(0.21)	(0.17)	(0.12)	(0.30)	(0.19)	(0.15)
Increase	0.20	0.70	-0.02	0.10	0.42	0.65	0.16	0.36
(sd)	(0.12)	(0.32)	(0.20)	(0.16)	(0.12)	(0.30)	(0.16)	(0.13)

Table 1: Proportions correct (standard deviations) free recall (FR), word completion (WC), cued recall with one word part (CR1), and with two word parts (CR2), averaged over 25 artificial subjects.

Simulation 2

Procedure. The procedure was the same as in Simulation 1, except that anterograde amnesia was simulated by artificially lesioning the model after pre-experimental learning. This resulted in eliminating elaboration learning. Consequently, there was only base rate learning and no random activation spread. This artificial lesioning may be somehow analogous to the hippocampus and amygdala damage responsible for anterograde amnesia (e.g., Mishkin, 1978). During testing the random activation spread was restored (but not the increased learning rate), so that different words could be produced for free recall.

Results and discussion. Performance on almost all tasks was reduced by the lesion (see Table 2). Phaf (1994) found a reduction on free recall of both HF words and LF words, but no reduction on word completion performance. LF words, moreover, now showed a higher level of free recall than HF words. These differences may be explained by the fact that after resolution of competition in CALM Map a

	High-frequency words				Low-frequency words			
	WC	FR	CR1	CR2	WC	FR	CR1	CR2
Base rate	0.53	0.00	0.48	0.52	0.26	0.00	0.27	0.24
(sd)	(0.13)	(0.00)	(0.16)	(0.15)	(0.15)	(0.00)	(0.15)	(0.13)
Experiment	0.61	0.26	0.54	0.62	0.44	0.34	0.43	0.48
(sd)	(0.11)	(0.21)	(0.13)	(0.12)	(0.08)	(0.19)	(0.13)	(0.09)
Increase	0.08	0.26	0.06	0.10	0.18	0.34	0.16	0.24
(sd)	(0.14)	(0.21)	(0.18)	(0.16)	(0.17)	(0.19)	(0.15)	(0.13)

Table 2: Proportions correct (sd) free recall (FR), word completion (WC), cued recall with one word part (CR1), and two word parts (CR2) of the amnesic artificial subjects.

neighborhood of nodes remains active, whereas in CALM only one node remains active. The proportion of elaboration/activation learning, therefore, changed in CALM Map, so that, even in non-amnesic learning, storage would rely more on activation learning than in CALM. Eliminating elaboration learning in CALM Maps, therefore, had smaller effects than in CALM modules.

Retroactive Interference

Forgetting is often seen as the result of interference by intervening material. Graf and Schacter (1987), however, found that interference affected cued recall and free recall performance, but did not affect the performance on word completion. In a study by Tulving, Schacter, and Stark (1982) the priming effect in a word-fragment completion task was still present after one week, but recognition performance dropped sharply over the one week delay.

Intervening material may particularly affect item-context associations, because there may be much overlap between the contexts of the stored material and the intervening material. It is as if more words are subsumed under the same context. Word completion is less affected, because intra-item associations have less overlap with the intervening material. Item-context associations in the model, moreover, are more subject to elaboration learning than intra-item associations, so that the dissociation resulting from interference may be sharpened.

In the first simulation (Simulation 3) a set of nonpresented words was presented as intervening material. In the second simulation (Simulation 4), random intervening material was presented between experimental learning and testing.

Simulation 3

Procedure. Because this simulation did not require distinction between high- and low-frequency words, the number of presentations during pre-experimental learning was equal for all twenty words (600 times in random order under all six contexts for 25 iterations). In the second stage the artificial subjects received (after pre-presentation of the experimental context) a list of ten words (word 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20) once in random order under the experimental context. The interference manipulation consisted of presenting the ten words (word 1, 3, 5, 7, 9, 11, 13, 15, 17, and 19) not presented in the second stage eight times in every non-experimental context in random order for 25 iterations. Five interference conditions were created by repeating the presentation of 480 intervening words to simulate increasing amounts of interference.

Results and discussion. Interference resulted in a decline of both free recall and word completion performance (Table 3). Word completion even decreased below base rate. This problem was caused by the limited number of words available in the lexicon. All ten intervening words had word parts (in particular, also the cue in word completion) in common with the experimental words. After sufficient presentation the association of the intervening words with word-part-1 had become stronger than of the experimental words with that word part. In general, both word completion and free recall showed retroactive interference, because there was overlap between experimental and intervening material both in the item-context and the intra-item associations. In Simulation 4 this overlap was reduced by presenting random patterns as intervening material.

	Free recall		Word completion	
	Test (sd)	Increase (sd)	Test (sd)	Increase (sd)
Base	0.00 (0.00)	0.00 (0.00)	0.39 (0.12)	0.00 (0.00)
Experiment	0.57 (0.32)	0.57 (0.32)	0.67 (0.11)	0.28 (0.11)
Interference 1	0.39 (0.24)	0.39 (0.24)	0.40 (0.13)	0.02 (0.10)
Interference 2	0.20 (0.15)	0.20 (0.15)	0.25 (0.14)	-0.14 (0.10)
Interference 3	0.09 (0.08)	0.09 (0.08)	0.14 (0.10)	-0.25 (0.09)
Interference 4	0.04 (0.06)	0.04 (0.06)	0.09 (0.08)	-0.30 (0.14)
Interference 5	0.02 (0.05)	0.02 (0.05)	0.04 (0.06)	-0.34 (0.13)

Table 3: Proportions correct (sd) free recall and word completion as a function of repetition of intervening material (presenting the ten not experimentally presented words).

Simulation 4

Procedure. The first and second stage were the same as in Simulation 3. New intervening material was created by randomly presenting word input in each input module. From the 10,000 word parts combinations possible, 480 words were randomly selected and presented without a context for 25 iterations each. Again five conditions of increasing interference were tested by presenting more intervening material.

Results and discussion. Only free recall performance (see Table 4) now showed a decline and word completion performance remained constant. The simulation results appear to be more similar to experimental results (e.g., Tulving, Schacter, & Stark, 1982). This simulation may be more realistic than the previous one, because in general intervening material does not share large numbers of word parts with experimental material. When there is such overlap, however, also word completion shows retroactive interference effects (Wolters, personal communication). The overlap in item-context association is caused by the reinstatement of the experimental context during presentation of the intervening material. Immediately after presentation of the experimental list, the experimental context has a high change of being activated, through the (bi-directional) connections from the word-CALM Map.

The foregoing two simulations (and the experimental results) actually stress the importance of compatibility

	Free recall		Word completion	
	Test (sd)	Increase (sd)	Test (sd)	Increase (sd)
Base	0.00 (0.00)	0.00 (0.00)	0.39 (0.12)	0.00 (0.00)
Experiment	0.57 (0.32)	0.57 (0.32)	0.67 (0.11)	0.28 (0.12)
Interference 1	0.53 (0.32)	0.53 (0.32)	0.67 (0.11)	0.28 (0.12)
Interference 2	0.54 (0.31)	0.54 (0.31)	0.68 (0.11)	0.30 (0.13)
Interference 3	0.54 (0.33)	0.54 (0.33)	0.69 (0.13)	0.30 (0.09)
Interference 4	0.48 (0.33)	0.48 (0.33)	0.67 (0.13)	0.28 (0.08)
Interference 5	0.45 (0.30)	0.45 (0.30)	0.64 (0.13)	0.25 (0.13)

Table 4: Proportions correct (sd) free recall and word completion as a function of intervening material. Interference consisted of presenting random word patterns.

between learning (and interference) and testing. If there is little overlap between the connections strengthened by the intervening material and the connections addressed at testing, there will be little interference. When there is much overlap there will be much interference, irrespective of whether it concerns an implicit or an explicit test. The ELAN-1 model thus also implements a particular type of study-test compatibility account and already combines two different accounts for the memory dissociations.

Focused vs. Divided Attention

Divided attention during learning is expected to mainly affect explicit memory performance and not implicit memory performance, because the formation of new item-context associations may be hindered by concurrent activity. The strengthening of old intra-item associations is not hindered by this activity. Similar to the interference simulation the number of items subsumed under the context-cue will get larger due to dividing attention, but the associations within items will not be weakened as long as the representational components of the concurrent activity do not overlap with those of the items. Elaboration learning, which primarily works on item-context associations, will again sharpen the contrast between implicit and explicit memory performance in this task. Such differential effects of divided attention were obtained in a dichotic listening task by Eich (1984) and by Phaf (1994) with visual presentation of words. Wolters and Prinsen (1997), however, also found an effect on divided attention during learning on word completion, only when the concurrent load was very high.

Simulation 5

Procedure. The first stage was the same as in Simulation 3. In the second stage, there were three conditions: one focused attention condition, and two divided attention conditions. In one divided attention condition there was a low simultaneous load, in the other a high simultaneous load. To simulate the three conditions, the artificial subjects were copied twice. After pre-presentation of the experimental context, all groups received a list of ten words (word 1, 3, 5, 7, 9, 11, 13, 15, 17, and 19) in random order under the experimental context. In the focused attention condition all word part input-nodes that did not belong to these words had zero activation. In the first divided attention condition these nodes had a (uniformly distributed) random activation between 0.0 and 0.2, in the second between 0.0 and 0.4.

Results and discussion. In principle, the simulation showed the expected dissociation. Free recall performance decreased with the load in the divided attention conditions (see Table 5). Word completion performance even increased in the first divided attention condition relative to the focused attention condition, whereas it strongly decreased in the second divided attention condition. This may be an elaboration effect due to the concurrent activity in the model. For low loads elaboration is increased, so that existing intra-item associations may be strengthened additionally. For stronger concurrent activity the increased random activations may tend to disrupt existing associations, so that new representations may be formed for the old words. Free recall may then be reduced by divided attention, not because of the formation of item-context associations is hindered but because many item-context associations are made to nonrelevant material.

	Focused attention		Divided attention I		Divided attention II	
	WC	FR	WC	FR	WC	FR
Base rate	0.42	0.00	0.36	0.00	0.24	0.00
(sd)	(0.10)	(0.00)	(0.13)	(0.00)	(0.12)	(0.00)
Experiment	0.70	0.59	0.77	0.39	0.14	0.07
(sd)	(0.13)	(0.32)	(0.13)	(0.21)	(0.12)	(0.09)
Increase	0.29	0.59	0.42	0.39	-0.10	0.07
(sd)	(0.12)	(0.32)	(0.16)	(0.21)	(0.15)	(0.09)

Table 5: Average proportions correct (sd) free recall (FR) and word completion (WC) in the three attention conditions.

General Discussion

Even in this very simple model, the possibilities for simulating actual memory experiments have not been exhausted. Further simulations with this model have, for instance, been performed of massed vs. spaced repetition effects and of read vs. generate effects. Due to space considerations these simulations were not reported here. The massed vs. spaced effect could be simulated reasonably well when massed and spaced conditions were presented in different lists. For word completion after generation no suitable operationalization could be found. Free recall after generation of words was, however, clearly higher than after reading the words in the model, which mirrors experimental findings.

The new ELAN-1 model with CALM Maps improves on the old model with CALM modules not so much in the number of simulation possible, but in the more fine-grained and subtle representations allowed by the topological ordering mechanism. Small shifts in context, which are sometimes postulated to play a role in forgetting, may in principle be simulated in this type of model. Very detailed input of words, for instance on the letter level, can more easily be accommodated in such a model. The CALM Map has one further advantage over CALM modules for actual simulations of experiments. The topological map tends to stretch its representations as far apart as possible, thus creating representations on the intervening nodes which actually interpolate between the neighboring representations (Phaf *et al.*, Submitted). Representations may be created for patterns that have not actually been presented. This property may, for instance, be useful in simulations of memory experiments where there are semantical relations between words. Such a network may be able to organize material according to meaning when only a limited number of examples is given.

Although the model may be very limited as a model for real subjects and the simulations differ in many details from real experiments, the present model was able to produce results that were similar to human findings in many respects. Full quantitative simulations can, of course, not be obtained in this framework. A more complicated model would probably do better and be able to simulate still more tasks. But even with the present model it is already possible to simulate, for instance, threshold identification tasks and probably only small extensions would be required to simulate recognition tasks. It should also be noted that even when quantitative fits were obtained with the model, this would have little theoretical significance. The model uses so many shortcuts and simplifications, such as the type of input, the nature of representations etc., that this could only be based on an empirical fit and would not reflect the theoretical value of the model. The strategy used for these simulations was different. After some preliminary simulations to check for global behavior of the model, the parameters were fixed and remained constant for all further simulations. No effort was spent to improve the simulation results by further adjusting the parameters. It cannot be excluded that a parameter set can be found that yields even better results.

Even when the model simulates the experiments successfully, this does not mean that the human system does these tasks in the same manner. Simulations with this model, primarily implementing activation/elaboration learning, merely adds weight to this position when comparing it to the other two positions. It is entirely possible that a model implementing multiple memory systems could also simulate these types of tasks successfully. In our opinion, however, such a model would also have to take recourse to different processes in the different systems, thus actually combining multiple memory systems and multi-process approaches. Also in our model the two types of memory tests are performed partly in different regions of the network. The modules in our model are, however, heavily interconnected and cannot be seen as anatomically separate or as functioning independently. Elements of a study-test compatibility account can also be found in the model. Retrieval through a particular path in the network is facilitated when the connections in this path have been strengthened initially during learning. The implementation of a computational model for implicit and explicit memory tasks thus leads to the finding that it is very hard to make a strict and exclusive distinction between the three alternative accounts.

The three positions from memory psychology are merely conceptual models which offer no guarantee that they actually produce the phenomena they purport to be able to explain. Computational models may be one step closer to establishing clear links between theory and experimental results. For their construction they require specification of many details which may have been overseen in the conceptual models. The further specification of processes required by computational models may not only be useful for memory psychology but may also lead to optimalization of artificial learning methods.

References

Eich, E. (1984) Memory for unattended events: remembering with and without awareness. *Memory and Cognition, 12,* 105-111.

Graf, P. & Mandler, G. (1984). Activation makes words more accessible, but not necessarily more retrievable. *Journal of Verbal Learning and Verbal Behavior, 23,* 553-568.

Graf, P. & Schacter, D.L. (1987). Selective effects of interference in implicit and explicit memory for new associations. *Journal of Experimental Psychology: Learning, Memory and Cognition, 13,* 45-53.

Kohonen, T. (1982). Self-organized formation of topologically correct feature maps. *Biological Cybernetics, 43,* 59-69.

MacLeod, C.M. & Kampe, K.E. (1996). Word frequency effects on recall, recognition, and word fragment completion tests. *Journal of Experimental psychology: Learning, Memory and Cognition, 22,* 132-142.

Mishkin, M. (1978). Memory in monkeys severely impaired by combined but not by separate removal of amygdala and hippocampus. *Nature, 273,* 297-298.

Murre, J.M.J., Phaf, R.H., & Wolters, G. (1992). CALM: Categorizing and learning module. *Neural Networks, 5,* 55-82.

Phaf, R.H. (1994). *Learning in natural and connectionist systems.* Dordrecht: Kluwer Academic Publishers.

Phaf, R.H., Tijsseling, A.G., & Lebert, E. (Submitted). *Self-organizing CALM Maps.*

Phaf, R.H. & Wolters, G. (1996). Elaboration effects in implicit and explicit memory tests. *Psychological Research, 58,* 284-293.

Raccuglia, R.A., & Wolters, G. (1996). Connectionist modeling of implicit and explicit memory tasks. In: J. Hoffmann & A. Sebald (Eds.), *Cognitive psychology in Europe* (pp. 131-132). Berlin: Pabst Science Publishers.

Richardson-Klavehn, A. & Bjork, R.A. (1988). Measures of memory. *Annual Review of Psychology, 39,* 475-543.

Roediger, H.L. III & Blaxton, T.A. (1987). Effects of varying modality, surface features, and retention interval on priming in word fragment completion. *Memory and Cognition, 15,* 379-388.

Schacter, D.L. (1987). Implicit memory: history and current status. *Journal of Experimental psychology: Learning, Memory, and Cognition, 13,* 501-518.

Tulving, E. & Kroll, N. (1995). Novelty assessment in the brain and long-term memory encoding. *Psychonomic Bulletin and Review, 2,* 387-390.

Tulving, E. & Schacter, D.L. (1990). Priming and human memory systems. *Science, 247,* 301-306.

Tulving, E., Schacter, D.L., & Stark, H.A. (1982). Priming effects in word fragment completion are independent of recognition memory. *Journal of Experimental psychology: Learning, Memory, and Cognition, 8,* 336-342.

Van Immerzeel, M. (1996). *Simulations with a connectionist model for implicit and explicit memory tasks.* Master's thesis. University of Amsterdam, The Netherlands.

Wolters, G., & Prinsen, A. (1997). Full versus divided attention and implicit memory performance. *Memory and Cognition,* In press.

Appendix

Weights and parameters of the ELAN-1 model: up, 0.5; flat, -1.0; high, -2.0; low, 0.4; AE, 1.0; strange, 0.25; inter, 0.5; AV, 1.0; VA, 3.0; reset, 2.0; VV, 0.4; output, 2.0; k, 0.25; L, 2.0; K, 1.0; d, 0.0001; $w_{\mu E}$, 0.0005; c_h, 0.05; c_l, 0.005; A, 8.8; B, 10.0; σ in word-CALM Map, 5.0; σ in context-CALM Map, 3.0 (for description of parameters see Murre *et al.*, 1992; Phaf *et al.*, Submitted; Van Immerzeel, 1996).