Anticipatory Semantic Processes

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Abstract

Why anticipatory processes correspond to cognitive abilities of living systems? To be adapted to an environment, behaviors need at least i) internal representations of events occurring in the external environment; and ii) internal anticipations of possible events to occur in the external environment. Interactions of these two opposite but complementary cognitive properties lead to various patterns of experimental data on semantic processing.

How to investigate dynamic semantic processes? Experimental studies in cognitive psychology offer several interests such as: i) the control of the semantic environment such as words embedded in sentences; ii) the methodological tools allowing the observation of anticipations and adapted oculomotor behavior during reading; and iii) the analyze of different anticipatory processes within the theoretical framework of semantic processing.

What are the different types of semantic anticipations? Experimental data show that semantic anticipatory processes involve i) the coding in memory of sequences of words occurring in textual environments; ii) the anticipation of possible future words from currently perceived words; and iii) the selection of anticipated words as a function of the sequences of perceived words, achieved by anticipatory activations and inhibitory selection processes.

How to modelize anticipatory semantic processes? Localist or distributed neural networks models can account for some types of semantic processes, anticipatory or not. Attractor neural networks coding temporal sequences are presented as good candidate for modeling anticipatory semantic processes, according to specific properties of the human brain such as i) auto-associative memory; ii) learning and memorization of sequences of patterns; and iii) anticipation of memorized patterns from previously perceived patterns.

Keywords - anticipations - attractor neural networks - context - dynamic memory - eye movements – priming - reading - semantic processes –

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1 Semantic Processes as Cognitive Representations and Anticipations

Why anticipatory processes correspond to cognitive abilities of living systems? To adapt to complex environments perceived as sequences of events (e.g., objects, scenes, and behaviors), living systems must both represent and anticipate in memory events occurring in the environment. Cognitive processes must allow rapid and efficient adapted behaviors increasing the survival of the animal or human living system (e.g., saving time in escaping a predator or catching a prey), which rely on the general definition of anticipatory systems (Dubois, 1998a; Rosen, 1985). Furthermore, cognitive anticipations rely on the concepts of incursion and hyperincursion in memory, for which multiple potential future states are activated in the system, one of them being selected (Dubois, 1996, 1998b). Indeed, the adoption of a behavior adapted to a given perceived event implies a selection among several internal representations of possible behaviors represented as sensory-motor meshed patterns (Glenberg, 1997). These enaction processes (Varela, Thompson, Rosh, 1999) on embodied representations of sensory-motor loops (see Berthoz, 1996) are based on associations, within the cognitive system, between perceived events and patterns of action. Within systemic interactions between a living system and its environment, perceived events in the environment would lead to selection in memory of meshed patterns representing adapted behaviors. For this aim, perceived events must be faithfully recognized by the cognitive system, and must also allow anticipations of possible future events. Within the framework of oculomotor behavior, for example, oculomotor pursuit and saccade to targets are constrained by both faithfull perception of target position and anticipation of the future target position (see Kowler, 1990; O'Regan, 1990). A synergy between representation of current position and anticipation of future position allows an adapted oculomotor behavior in which the eyes do not land on the perceived target position at the onset of the saccade, but land on the target position anticipated at the offset of the saccade (i.e., the target displacement during the saccade is anticipated).

The cognitive system also acts in a more proactive way in simulating possible actions and evaluating their consequences on events perception (Berthoz, 1996; Glenberg, 1997). The anticipation of simulated consequences of actions are coded as internal maps in a dynamic memory (Droulez, Berthoz & Vidal, 1985; Droulez & Berthoz, 1988; see Viviani, 1990; in Berthoz, 1996). They constitute simulations of actions which have to be confirmed during the realization of the action for an adapted behavior. Then anticipations imply dynamical sequences of sensory-motor meshed patterns, which suppose that anticipatory processes orient the system toward adapted behaviors as a function of both the currently perceived event and anticipated events. According to a description of thinking as inhibited and not realized internal actions, not only a selection of an adapted behavior to a current perceived event has to be made, but also an internal simulation of adapted sequences of actions involving possible events to happen in the environment, as well as possible changes in the predicted patterns due to the own system predicted behavior. In this way anticipatory processes are directly oriented to the selection of adapted behaviors. The cognitive system can then be seen as an enactive simulator which anticipates events and which checks for the realization of the adapted behaviors in comparing them with simulated behaviors (Cornilleau-Perez & Droulez, 1993).

To select behaviors adapted to the perceived patterns in the environment, the cognitive system has to accomplish two fundamental semantic processes: (i) to faithfully perceive and semantically recognize events in the environment; and (ii) to dynamically anticipate possible future events. For this the system has to represent in memory the complexity of its environment in storing associations between perceived events, based on statistical correlation between events occurring in the environment. Spatial temporal correlations would then lead to associations in memory of the most frequently co-occurring patterns (i.e., at a given time in space or in temporal sequences). Given that correlations between events in the environment are stored as associated events in memory, a given event would be represented as associated to other events, which is a prerequisite for faithful representation of events, and activate events frequently occurring in the same sequence, which is a prerequisite for anticipatory processes.

The purpose of this article is to review experimental results and theories in the field of semantic processing, in order to identify and define anticipatory processes and discuss neural network modeling of anticipatory semantic processes. In Section 1 we present methods and techniques used in experimental psychology to investigate semantic processing, before discussing different types of semantic processes with regards to experimental data on semantic representations and anticipations. The two main types of semantic processes are distinguished in order to isolate their relative interests for adapted cognitive abilities. In Section 2 we concentrate on the specific dynamic properties of anticipatory semantic processes reported in the experimental literature, such are their time course and activatory or inhibitory effects on anticipated events in memory. This allow to define precisely the spatio-temporal properties of anticipatory processes, which are important to better understand the adaptive properties of anticipatory processes and for further modeling. In Section 3 we present the structure and functioning of an attractor neural network model which can learn and store in memory sequences of perceived patterns, and anticipate future patterns from perceived patterns.

1.1 Experimental Study of Semantic Processes

How to investigate dynamic semantic processes?

For the purpose of experimentally investigating semantic processing, the research in cognitive psychology presents methodological and theoretical advantages. Indeed, experimental studies allow to i) control the semantic environment influencing the semantic processes in memory to be studied; ii) use methodological tools allowing the observation of semantic processes influencing human behavior; and iii) report a variety of well known processes defined as a function of their spatial and temporal properties within the theoretical framework of semantic processing.

i) The associations between word meanings in memory (concepts) are assumed to depend on the frequency of co-occurrence of the processing of the two concepts together (Conrad, 1972; Freedman & Loftus, 1971; Perlmutter, Sorce, & Myers, 1976). In the field of associative semantic memory and word processing, Spence and Kimberly (1990; see Landauer, Foltz, & Laham, 1998) experimentally shown that words in memory (i.e. occurring events: 'lion-danger') are associated as a function of their correlation in corpus of texts (i.e. the reader's environment: 'When I see a lion running at me, the danger makes me flee as quick as possible'). The association in memory can be experimentally measured in recording the percentage of cases (among numerous subjects) in which a target word ('danger') is given as the first coming in mind after reading of a prime word ('lion'). In the collected associative norms, high percentages of producing a given target word associated to a given prime word correspond to strong associations in memory. Experimental data (Spence and Kimberly, 1990; Landauer et al., 1998) show that the more two words are correlated in the textual environment (i.e. spatial correlation such as lexical distance between the two words, which corresponds to temporal correlation during sequential reading), the more they are associated in memory. Dynamic semantic processes can then be investigated as a function of semantic associations in memory, in experimentally testing the effects of a given prime word pattern (respectively 'lion' or 'cloud') on the processing of a subsequent associated or non-associated target word pattern (e.g., 'danger').

ii) To finely analyze the dynamic properties of semantic processes, experimental studies use specific methods of recording the reader's behavior while processing a target word. Eye movements on perceived events in the environment are a fundamental behavior in many living systems, in which a saccade to a given perceived pattern is a decision of action in response to a perceived event (Sokolov & Vinogradova, 1975, in Berthoz, 1996). Several oculomotor behaviors can be preprogrammed in parallel in memory and kept inhibited, corresponding to anticipations leading to simulations of the consequences of the saccades, one of them being actually realized when selected and des-inhibited (Sheliga, Riggio, & Rizzolatti, 1994). During reading, a reader's oculomotor behavior can be finely tuned to word-events perceived in a sentence, and vary on a target word as function of the preceding semantic context prime. Reading speed, fixation duration, landing site, and refixation probability on a target word, are different oculomotor behaviors adopted on perceived word event. Experimental settings allow to record reader's oculomotor behavior during sentence reading, and to analyze the effects of a preceding controlled prime word (e.g., 'lion') on the processing of a currently processed target word (e.g., 'danger'). In other types of experiments readers do not read full sentences but word sequences presenting a single prime word sequentially followed by a single target word. In these isolated word priming experiments, the reader processes the prime word (e.g., 'lion') and subsequently adopts a given behavior on the target word. This behavior can be a naming task in which the reader has to pronounce the target word as fast as possible; or a lexical decision task in which a 'yes' key is pressed when the target is a word (i.e., 'danger') and a 'no' key is pressed when the target is not a word (i.e., 'drojur').

Processing times on a target words (fixation duration in reading and naming or lexical decision time in word priming) are recorded as a function of different controlled semantic context primes (e.g., associated vs. non-associated). Mental chronometry data show that the time and accuracy of the target word processing are influenced by the preceding semantic context prime (see Balota & Rayner, 1991; Neely, 1991; Rayner & Balota, 1989, for reviews). A perceived target word ('danger') is more rapidly processed (about 550 ms) if already activated in memory accordingly to an associated preceding context ('lion'), and is more slowly processed (about 600 ms) when preceded by a non-associated context ('cloud'). Then the observed behaviors adopted on a target word are good indicators of the effects of cognitive processes triggered by the reading of a controlled context prime and modifying the target's status in memory.

iii) A corner stone concerning theoretical models of semantic processing rely on the representational and/or anticipatory properties of the cognitive system (see Neely, 1991 for a review). On the one hand, theories of semantic representations assume that perceived word meanings are faithfully and fully accessed in memory whatever the semantic context. On the other hand, theories of semantic anticipations assume that perceived word meanings can be differentially accessed in memory as a function of context-based anticipations. These two main theoretical views present both advantages and disadvantages with regards to adaptive properties of the cognitive system, such as speed of perceptive processing and reliability of the representations.

1.2 Semantic Representations of Perceived Words

To cope with the complexity of their environment, a cognitive system must be able to reliably represent in memory events in the environment. For example, if the event 'lion' is correlated to 'danger' and not to 'cloud' in the environment, a faithful representation in memory must be associated to the one of 'danger' and not of 'cloud'. And also, if the event 'lion' is once perceived at the same time as 'rain', its meaning in memory still must be associated to 'danger'. In other words, the situations in which an event is perceived ('lion') can vary ('rain', 'zebra', etc.), but must not impair the association with correlated events ('danger'). More generally, faithful internal representations must allow the system to reliably recognize (i.e. access in memory) perceived events whatever their current context. This main cognitive property of faithful referential semantic representations can allow the system to access events in memory accordingly to their semantic associations with other events and not to the variable specific context currently encountered. Then access processes from perceived patterns to their representations in memory must present some independence from the context. This allow the system to adopt behaviors as a function of whole meaning of the actually perceived events faithfully recognized whatever their context.

To discriminate if the context can modify or not the type of associations in memory made with a perceived word, that is if a word (meaning) is associated in memory with the same other words (meanings) whatever the context or not, experimental studies investigated context effects on the access in memory of ambiguous words such as ‘bank’. The ambiguous words meaning presented two types of semantic associates (‘river’ or ‘money’), and was presented after a context favoring one or the other of the two meanings in memory (‘water’ or ‘safe’). Then one of the two possible associates was presented and processing times were recorded. Results showed that whatever the context (‘water’ or ‘safe’) of the ambiguous word (‘bank’), all the associates in memory (‘river’ and ‘money’) were rapidly activated in a first time, the one not corresponding to the context being slowly inhibited in a second stage. These results argue for a context-independent hypothesis assuming that word meanings are fully accessed in memory before context effects can select one of the meanings (Onifer & Swinney, 1981; Kintsch, 1988; Swinney, 1979; see also Fodor, 1983). This would suggest that readers faithfully represent the whole meaning of an ambiguous word whatever the context, and that they do not anticipate one of the meanings according to the previous context. This implies that a word meaning is accessed in memory whatever its current context, and then that a perceived pattern is always recognized in association with the same other representations in memory (‘lion’-‘danger’).

Models of context-independent word processing are proposed which account for non-anticipatory semantic processes. Norris (1986) plausibility checking (PC) model, restrospective (i.e. non-anticipatory) semantic matching (SM) processes (Keefe & Neely, 1990; Neely and Keefe, 1989), familiarity judgement (FG) model (Ratcliff and McKoon, 1988, 1994; McKoon & Ratcliff, 1992; see Gillund & Shiffrin, 1984), assume that semantic processes occur after both the prime and target are fully accessed in memory. According to these models, priming effects are not due to anticipatory preactivation of associated target words in memory before its actual perception, from the reading of a previous prime, but from strategies of semantic judgement of the association between the prime and target occurring after the target lexical access. The processing of the word pair would then influence the behavioral lexical decision response to the target word (Balota & Chumbley, 1984).

The advantage would be to access the words whole meanings in memory independently of their context, the context inducing semantic judgements only after perception led to an activation of the word meaning in memory. Associates to a perceived word pattern would be activated in memory in a systematic way, accordingly to the semantic associates in memory based on stable learned association, and without distortion from variable current contexts. In this case faithful internal representations reliably represent events in the environment the way they are perceived, in order to semantically represent them whatever their context and to adopt behaviors adapted to the whole meaning of a given event.

1.3 Semantic Anticipations of Predicted Words

To adapt to their environment, cognitive systems must be able not only to faithfully represent in memory events perceived in the environment, but also to anticipate and predict events not yet perceived but that can probably occur in the environment. Then anticipatory semantic processes would take into account of the context to predict possible events not yet perceived.

Semantic anticipations can preactivate the representation of a word in memory, and then enhance and facilitate its perceptive processes as well as adapated motor behavioral responses. For example, context effects on behavioral responses vary with word perceptive properties, being of larger magnitude on visually degraded target words, either by diminishing their visual intensity, by presenting them surrounded by visual noise, by masking them with rows of Xs or letters (Becker & Killion, 1977; Massaro, Jones, Lipscom, & Schols, 1978; Meyer, Schvaneveldt & Ruddy, 1975; Sperber, McCauley, Ragain, & Weil, 1979; Stanovitch & West, 1979, 1983). Furthermore, studies show that context effects interact with target word frequency, the perceptual processing of low frequency words being more enhanced by the semantic context than the one of high frequency words (Becker, 1979; Schuberth & Eimas, 1977; Schuberth, Spoehr & Lane, 1981). These results suggest that semantic context effects could then be due to actual anticipations leading to preactivations of target words in memory, enhancing perceptive lexical access (reducing processing times) when target words are already activated in memory by a previous context.

The context-dependent view posits that actual anticipatory context effects can emerge quite early in the process of word recognition, and that they occur before lexical access has been completed and bias the word meaning accessed in memory (Lavigne & Dubois, 1999; Lavigne, Vitu & d'Ydewalle, in press; Sharkey & Sharkey, 1992; Thompson-Schill, Kurtz & Gabrieli, 1998; VanVoorhis & Dark, 1995;). Tabossi (1988a-b; Tabossi & Zardon, 1993) tested context effects on the processing of words ('gold') presenting different associates in memory ('hair' and 'metal'), corresponding to different facets in their meaning. Results show that a strongly constraining (strongly associated to one of the associates in memory) preceding context ('girl') can influence lexical access in selecting the adequate associate ('hair') to the target word ('gold') before its full lexical access, given that the associate inadequate with the context ('metal') was not activated by the processing of the target word ('gold'). When the semantic context is predictive enough, anticipatory context effects can then facilitate lexical access to the meaning of the target word adequate to the context.

The possibility for anticipatory context effects to modify lexical access (Tabossi, 1988a-b; Tabossi and Zardon, 1993), or not (Swinney, 1979; Onifer & Swinney, 1981), (Paul et al., 1992) would depend on the relative strength of the associations in memory between a target words meaning (i. e. its associates) and the current context. This would allow the system to access a part of the words meaning adequate to the context as a function of both the predictability of the context and the associations in memory. The two main hypothesis of context-independence and context-dependence of word processing are then not mutually exclusive and can then be complementary. Perceived patterns which were already anticipated from a strongly constraining context can be processes faster without the need of faithful verification, and perceived patterns which were not strongly anticipated would be more slowly faithfully processed. Then anticipations appear as a main property of cognitive systems, faithful representations being necessary only in cases when anticipations failed to predict actually perceived patterns.

Given the assumption that perceptive lexical access is influenced by contextual anticipations, different models can account for semantic anticipatory processes in memory. Both models of automatic spreading activation (ASA; Anderson, 1983; Collins & Loftus, 1975; Collins & Quillian, 1969; see Logan, 1988a,b) and of expectancy mechanisms (EM; Neely, 1976, 1977; Posner & Snyder, 1975b) assume that processing of a context word would trigger forward anticipatory processes activating associated target words in memory, before its actual perception and lexical access. According to these models, the status in memory of a given target word depends on anticipations triggered from the previous context. Anticipations are confirmed when the anticipated word is actually perceived, leading to enhanced perceptive lexical access and faster adapted behaviors.

1.4 Experimental Evidences for Anticipatory Semantic Processes

Concerning experimental data reporting semantic anticipatory processes, the question must be raised of whether experimental procedures are appropriate to investigate the effects of context on *vs*. after the access to the word meaning. Indeed, long response times (about 500ms for lexical decision, naming, and gaze durations) might allow readers to use non-anticipatory strategies after the target word has been accessed (Balota & Chumbley, 1984; de Groot, 1984; Forster, 1981; Monsell, 1991; Thompson-Schill, Kurtz & Gabrieli, 1998; VanVoorhis & Dark, 1995), and before the response itself during the long reaction time (Balota & Chumbley, 1984; Neely, 1991; Ratcliff and McKoon, 1988). Further experimental evidences for anticipatory semantic processes must then show early priming effects influencing the lexical access stage of the word meaning in memory:

i) The observation of unconscious semantic processing could argue for the possibility of anticipations, given that subliminal priming effects are triggered by an unconscious prime presented very briefly (a few milliseconds) and followed by a visual mask. No conscious post-access judgement of familiarity of the prime-target pair can be performed. Several studies report subliminal anticipatory semantic processes on response times to target words preceded by a subliminal prime. The prime could be processed unconsciously because it was very briefly presented (about 10 to 40 ms) and/or masked by a letter string replacing it rapidly (Balota, 1983; Carr, McCauley, Sperber & Parmelee, 1982; Fischler & Goodman, 1978; Fowler, Wolford, Slade & Tassinary, 1981; Hines, Czerwinski, Sawyer & Dwyer, 1986; Marcel, 1983); or because it was presented in parafoveal vision (Fuentes, Carmona, Agis, & Catena, 1994; Fuentes, & Ortells, 1993; Fuentes, & Tudela, 1992). Despite subliminal priming effects have been confirmed (Greenwald, Draine & Abrams, 1996) since the first methodological criticisms (see Cheesman & Merikle, 1984; Hollender, 1986), non-anticipatory theoretical alternatives can explain the observed data. Indeed, given that semantic processing can be subliminal, post-access semantic matching stages could also be unconscious. Ratcliff and McKoon's (1988, 1994; McKoon & Ratcliff, 1992) familiarity judgement model could possibly assume for unconscious semantic judgements accounting for subliminal but non-anticipatory and post-lexical priming.

ii) Given that no post-access familiarity judgement of the prime-target pair can be performed before the target is fully accessed in memory, experimental investigations of actual anticipatory semantic processes must allow to observe semantic priming effects during the lexical access of the target word, that is before its complete lexical access is achieved. This would be a strong argument for the existence of anticipatory semantic processes emerging early during the target words lexical access (Sharkey & Sharkey, 1992; Tabossi, 1988a-b ; Tabossi and Zardon, 1993; see also Thompson-Schill, Kurtz & Gabrieli, 1998; VanVoorhis & Dark, 1995).

The recording of oculomotor behavior during reading allow a fine analysis of the successive stages of processing a given target word (e.g., parafoveal preprocessing, first fixation durations, second fixation durations). This allows to test for semantic context effects occurring during the access stage, given that during reading words are partially processed in parafoveal vision before they are fixated (Balota & Rayner, 1983; Blanchard, Pollatsek & Rayner, 1989; Lima & Inhoff, 1985; Rayner & Morrisson, 1981; see Haber, 1976; Hochberg, 1970, 1975, 1976). Early priming effects on a target word during its parafoveal processing should be observable on a shift of the position where the eyes initially land onto the target word (the optimal viewing position, see Vitu, 1991; Vitu, O'Regan, & Mittau, 1990). A few studies report slight effects of semantic priming on landing site (Dubois & Sprenger-Charolles, 1988; Everatt & Underwood, 1992; Underwood, 1990), and in most cases the effects being observed might be attributed to target word properties (frequency or luminance) rather than to the preceding semantic prime. Controlling lexical variables (high-frequency target words) allowing a strong parafoveal processing of the target word (see Inhoff & Rayner, 1986 ; Vitu, 1991), Lavigne and Dubois, 1999 (Lavigne et al., in press) have reported that the eyes land further away in target words which are semantically associated to the preceding prime than in non-associated target words.

We might envisage that the following mechanisms underlie the observed effects of semantic context on saccade size. After reading of the prime, the system generates some predictions as to the upcoming target word which turns into a pre-activation of the target word and of the corresponding adapted motor saccade to this target (meshed pattern). If, when the eyes get closer to the target word, some letter-information from the word can be extracted in parafoveal vision, then both types of semantic and visual information can be combined and the target word will get more activated if both types of information are compatible (perceived and anticipated informations). When the system gets ready to move the eyes to the next word, a saccade is selected among anticipated preprogrammed saccades, on the basis of a contextual anticipations and low-level analysis of the visual configuration formed by parafoveally perceived word (see Vitu, 1991). If the perceived word is the anticipated target word, then the anticipated meshed pattern is selected (target word and corresponding saccade) and the adequate saccade is launched, adapted to both contextual anticipations and the perceived target word (see Haber, 1976;

Hochberg, 1970, 1975, 1976). The selection of the saccade might bring the eyes at a position which favors the extraction of the target's letters that could not be extracted in parafoveal vision on the prior fixation, and therefore helps speeding up the processing of the target word. This might also serve to bring the eyes closer to the next word, and therefore help starting the preprocessing of this word while processing of the target word is being achieved.

This finding suggests that the semantic processing of a word can occur during early stages of parafoveal lexical access (Everatt & Underwood, 1992; Fuentes, Carmona, Agis & Catena, 1994; Fuentes & Ortells, 1993; Fuentes & Tudela, 1992; see also McClelland & O'Regan, 1981). Given that the target words needed to be fixated foveally to terminate their processing, they were not fully identified in parafoveal vision. The fact that early context effects on the size of the saccade to the target word argue for the context-dependent hypothesis (Tabossi, 1988a,b; Tabossi & Zardon, 1993, see also Schwanenflugel, 1991; Schwanenflugel & LaCount, 1988; Schwanenflugel & White, 1991). Therefore context effects must lead to forward anticipation to influence perceptive word processing during the access stage (see Thompson-Schill, Kurtz & Gabrieli, 1998; VanVoorhis & Dark, 1995).

2 Time Course of Activatory and Inhibitory Anticipatory Semantic Processes

What are the different types of semantic anticipations?

Experimental data show the possibility for anticipatory semantic processes (see Neely, 1991; Lavigne & Dubois, 1999; Lavigne et al., in press), and theories of semantic processing support the idea that the brain is a simulator anticipating behaviors from perceived events (see Berthoz, 1996; Glenberg, 1997). Anticipatory semantic processes are then a main cognitive ability allowing prediction of future events which can occur in the environment. Anticipations can then enhance further perceptive and semantic processes and improve response behaviors, such as eye movements in reading. Anticipatory semantic processes can be experimentally tested and their specific properties as adapted cognitive abilities can be discussed within the theoretical framework of semantic priming processes. In this way we will now present experimental data on the different types of anticipatory processes and their respective time courses.

2.1 Activatory and Inhibitory Anticipatory Semantic Processes

Experimental data give more insight on the precise types of semantic anticipatory processes selecting anticipated patterns in memory. Studies on activatory and inhibitory semantic processes report data comparing response times on perceived word patterns (e.g. 'danger') preceded by either an associated ('lion'), a non-associated ('cloud') or neutral prime pattern ('xxxx' or 'mdcspf') (Becker, 1980, 1985; den Heyer, Briand & Smith, 1985; Favreau & Segalowitz, 1983; Lorch et al., 1986; Neely, 1976, 1977;

Smith, Brian, Klein & den Heyer, 1987; see Neely, 1991 for a review). Results show activatory context effects on target words preceded by an associated prime ('lion-danger': 550 ms) compared to targets preceded by a neutral prime ('xxxx-danger': 600 ms), and null or inhibitory effects on target words not preceded from a non-associated prime ('cloud-danger': 600 ms or 650 ms) compared to targets preceded by a neutral prime ('xxxx-danger': 600 ms). Within this framework, a neutral prime would not activate any associated patterns and run no anticipations in memory, giving a neutral baseline for the corresponding response times on targets (see Neely, 1991, p 279 for a discussion). Compared to this neutral baseline, a word prime would activate associated word patterns in memory before they are actually perceived. This correspond to semantic anticipations as preactivation of associated patterns. Activatory and inhibitory effects depend on how strongly a target can be anticipated from the prime, that is on how strongly the prime and target are associated in memory. Targets strongly associated to the primes are more activated (better facilitation on processing time) than weakly associated targets (Becker, 1979, 1980, 1985; den Heyer et al., 1985; Smith et al., 1987). By contrast, patterns non-associated to the prime would benefit equal or less global activation than when preceded by a neutral prime, leading to equal or longer response time corresponding to inhibitory effects.

2.2 Respective Time Courses of Activatory and Inhibitory Anticipatory Processes

In addition to the recording of reaction times, corresponding to behaviors adopted to the target word, mental chronometry also allows a good control of the time delay between the context prime and target (SOA = Stimulus Onset Asynchrony). Analysis of the reaction times onto the target word as a function of the delay between the context and the target word gives insights on the actual time course of semantic anticipations triggered in memory. Activatory and inhibitory semantic processes present different respective time courses, activation on predicted targets being fast and sustained through time and inhibition on non-predicted targets slowly increasing through time (Becker, 1980; den Heyer at al., 1985; Favreau & Segalowitz, 1983; Neely, 1976, 1977; Smith, et al., 1987). The time courses of activatory and inhibitory processes can then be studied across different time delays (SOA) between processing of the prime and of the target:

i) At short time delays (mean=200ms) activatory effects arise very rapidly in the same amount on strongly and weakly associated targets, reaching an asymptotic level which is higher for strongly associated than weakly associated target words (Lorch, 1982; Ratcliff & McKoon, 1981). More generally semantic priming effects arise on associated target words displayed shortly after processing of the prime (40-250 ms; Balota, Black & Cheney, 1992; Favreau & Segalowitz, 1983; Neely, 1976, 1977). This corresponds to the fact that associated targets are activated by the prime as soon as it is processed. By contrast, at shorts time delays no or weak inhibition occurs on non-associated targets.

ii) At long time delays (mean=1000ms), activatory processes are sustained long after processing of the prime on target associated to, or anticipated from, the prime

(2,000-3,250 ms: Balota et al., 1992; Becker, 1980, 1985; Lavigne & Vitu, 1997; Lavigne, Vitu & d'Ydewalle, submitted; Neely, 1976, 1977). Activatory processes on associated targets are also stronger at long delays than at short delays (Becker, 1980; den Heyer et al., 1985; Smith et al., 1987). Furthermore, when the time delay is long enough, slow inhibitory effects can be observed on target words which are not anticipated from the prime (den Heyer et al., 1985; Favreau & Segalowitz, 1983; Neely, 1976, 1977; Smith et al., 1987).

These results strongly suggest that rapid automatic spreading activation processes, depending only on the association between the prime and target, would allow rapid anticipations adapted to rapidly incoming new patterns to the cognitive system. Indeed, since the adaptation criteria of the anticipatory processes is mainly to save time in processing the perceived patterns, anticipations allow a rapid pre-activation in memory of possible upcoming word patterns in order to quickly enhance their processing and reduce their processing time.

2.3 Activatory and Inhibitory Anticipations in Processing Word Sequences

Semantic anticipatory processes trigger a preactivation in memory of possible upcoming words from the processing of preceding word. However, semantically associated words (e.g., 'lion' and 'danger') are frequently separated from each other by interposed words (e.g., 'fence'). In reading situations, the prime and target words presented in sentences or in texts are often separated by non-associated interposed words. It is then important to analyze semantic anticipatory processes during the sequential scanning of word. Indeed, in addition to the time delay elapsed between processing words which can modify the anticipatory processes made from the prime; non-associated words interposed between the prime and target can shift the anticipations made on possible upcoming target words (Balota et al., 1992; Lavigne & Vitu, 1997; Lavigne, Vitu & d'Ydewalle, submitted; Masson, 1991, 1995; Neely, 1976, 1977). Then, according to the two parameters occurring in sequential processing, association of the interposed word and time delay before processing of the target (see Neely, 1991), efficient anticipatory processes would have to adapt to sequences of words as a function of their associations and of the time course of their processing.

i) At short time delays between the interposed word and the target (150-300 ms), the target (e.g., 'danger') anticipated from the preceding associated prime ('lion') is perceived quickly after the non-associated interposed word ('fence'). In this case rapid activatory processes of the prime on the associated target still arise through the processing of the non-associated interposed word (Balota & Paul, 1996; Balota, Pollatsek & Rayner, 1985; Brodeur & Lupker, 1994; Duffy, Henderson, & Morris, 1989; Ehrlich & Rayner, 1981; Lavigne & Vitu, 1997; Lavigne, Vitu & d'Ydewalle, submitted; McNamara, 1994; Sereno & Rayner, 1992). Then it appears that at short time delays anticipations from the prime on associated targets in memory are not shifted by the processing of a non-associated interposed word.

ii) At long time delays between the interposed word and the target (1000-2000 ms), the target word is perceived later after processing of the non-associated interposed word. In this case activatory processes of the prime on the associated target are cancelled by the non-associated interposed word (Balota et al., 1992; Lavigne & Vitu, 1997; Lavigne-Tomps et al., submitted; McNamara, 1994; see Neely, 1976, 1977, Posner & Snyder, 1975a,b). Canceled priming effects by a non-associated interposed word are observed in word priming studies but not systematically in sentence reading studies. In the later the interposed words are neutral enough to not lead to actual shifts in the anticipations from the prime (Balota et al., 1985; Ehrlich & Rayner, 1981; Lavigne & Vitu, 1997; Lavigne et al., submitted), and the syntactic structure can help in keeping activated the anticipated target words despite the interposed words (O'Seaghdah, 1989; see Foss, 1982). However, priming effects can be canceled at long time delays during reading when the interposed words clearly introduce a topic shift in the anticipatory processes (Hyöna & Jarvella, 1994; Lavigne et al., submitted; Simpson, Peterson, Casteels, & Burgess, 1989).

Cancelled activatory effects correspond to inhibitory effects on previously anticipated targets, that is to shifts in the anticipations initially made from the prime. Then at long time delays, non-associated interposed words between the prime and target can shift the anticipations made on possible upcoming targets. The reading of the unrelated interposed word would lead subjects to anticipate different target words than from the previously read prime, and would therefore modify anticipations constructed earlier from the prime itself. The shift in the anticipations made on the target, first from the prime and secondly from the interposed word, is slower than the direct activatory anticipations initially made from the prime. Then global expectancy mechanisms involve both activatory anticipations and inhibition of anticipations. The fact that inhibitory effects (cancelled activations) leading to shifts in the anticipations are slower than activatory anticipations could suggest that non-associated word must shift anticipations of the system only if their duration is long enough compared to the previous anticipations, allowing the system not to shift anticipations on each new perceived event but to maintain more stable anticipations resistant to local non-anticipated events. Anticipations would then be shifted only when perceived patterns introduce global changes in the perceived environment in staying longer activated in memory. These anticipatory processes would then allow the cognitive system to be resistant to local changes in the environment or to adapt to more sustained changes in the environment by shifting anticipations.

3 Neural Network Modeling of Semantic Anticipatory Processes

How to modelize anticipatory semantic processes?

Neural networks have been proposed to modelize goal directed behaviors and/or anticipatory processes (Cruz, 1992; Dubois, 1996; Gossberg, Levine & Schmajuk, 1992; Levine, Leuven & Prueitt, 1992; Mobus, 1994). Within the specific framework of semantic processing defining precisely activatory and inhibitory anticipatory processes, the problem to be resolved by a good neural network model is to perform a spatial associative learning in memory of temporal sequences in the environment. The adequacy of the associative coding of temporal correlations and the learning abilities of semantic associations between words allowing anticipatory semantic processes.

3.1 Localist Automatic Spreading Activation (ASA) Models

The experimental data on activatory semantic priming lead to automatic spreading activation (ASA) models (Anderson, 1983; Collins & Loftus, 1975; Collins & Quillian, 1969). According to the structural properties of ASA models, they are localist models in the sense that a word meaning (concept) is coded by a single neuron which can be differentially linked to other neurons coding other word meanings. The strength of the association between two neurons depends on the frequency of co-occurrence of the two corresponding word meanings (Conrad, 1972; Freedman & Loftus, 1971; Perlmutter et al., 1976; Spence & Kimberly, 1990). The fundamental processing mechanism of the ASA models is the activation which can propagate from neuron to neuron as a function of the strength of their association. The time needed for activation to spread from a neuron to another is inversely related to the strength of the association (Anderson, 1983; Collins & Loftus, 1975; Posner & snyder, 1975). The ASA models account for the anticipatory properties of semantic processing, given that a neuron activated by the perceptive processing of its corresponding word can automatically activate associated neurons before their corresponding words have been perceived. However, though ASA models account for the positive relationship between amount of activation and strength of association, they can not account for basic priming effects such as (i) the time course of activation, (ii) inhibition, and (iii) interposition effects.

(i) Experimental data show that priming effects have the same speed for strongly and weakly associated words, only the asymptotic level of activation being higher for strongly associated words (Lorch, 1982; Ratcliff & McKoon, 1981). However ASA models predict amount of activation related to the associative strength, reaching a threshold from which activation is faster on strongly associated neurons than on weakly associated neurons.

(ii) The literature reports that inhibition can occur in some cases on non-associated target words (den Heyer at al., 1985; Favreau & Segalowitz, 1983; Lorch et al., 1986; Neely, 1976, 1977; Smith et al., 1987; see Neely, 1991 for a review). The processing properties of ASA models predict only spreading activation and no spreading inhibition between neurons.

(iii) Studies on processing sequences of words report that a non-associated interposed word can cancel the activation of a prime on an associated target (Lavigne & Vitu, 1997; Lavigne et al, submitted: Masson, 1991, 1995). The absence of spreading inhibition do not allow ASA models to predict inhibition from a non-associated interposed word compared to a neutral interposed stimulus (see Anderson, 1983, p104; Masson, 1995, p 9 for comments).

3.2 Distributed Memory (DM) Models

Distributed memory models (Masson, 1989, 1991, 1995; Sharkey, 1989, 1990; Sharkey & Sharkey, 1992; see also Grossberg & Stone, 1986; Hinton & Shallice, 1991) have been proposed to account for the data on word processing and/or semantic priming effects. To specifically account for the time course of anticipatory priming effects, Masson's DM model is derived from a Hopfield network (Hopfield, 1982; Hopfield & Tank, 1986; see Amit, 1989), in which word meanings (concepts) are not coded by single neurons but consist of patterns of activation across sets of several associated neurons. Each word is memorized in the distributed network as an attractor, i.e., a pattern of activation of a subset of neurons among the entire set, based on stronger associations between neurons coding for a same word than between neuron coding for different words. The attractors corresponding to words coded in memory are stable states of the network, which are learned by the model in increasing the associative strength between neurons coding for the same word according to a Hebb-like learning rule:

$$\Delta w_{ij} = \alpha\, n_i\, n_j$$

where w_{ij} represents the synaptic weight of the link between neurons i and j, and n_i and n_j represent the states taken on by neurons i and j when the word meaning is activated.

In DM models associated words share part of their coding neurons, each shared single neurons coding for a semantic feature common to the two words meanings. The attractor network can account for semantic priming effects in propagating activation from a word to part of another through shared neurons. Then processing properties of DM models allow a good account for the direct relationship between associative strength between words (number of shared neurons and associative strength between neurons), according to the rule of spreading activation across the network, in which the activation received by a neuron is a function of the on/off states of the other nodes and the strength of their association:

$$a_i = \Sigma\, n_j\, w_{ij}$$

where a_i represents the amount of activation directed to the neuron i, w_{ij} represents the synaptic weight of the link between neurons i and j, and n_j represent the state taken on by neuron j.

On the basis of these processing properties, DM models can account for the time course of basic activatory priming effects (Masson, 1991, 1995):

(i) In DM models the processing of a prime activates all neuron coding its meaning, including shared neurons coding the meaning of associated targets. The model well accounts for the time course of activation, given that activation spread rapidly toward all the associated neurons, including shared neurons also coding for associated words. The activation of the shared neurons (i.e., of the associated word) reaches a higher asymptotic level for strongly associated words than for weakly associated words, on the single basis of the different numbers of shared neurons and not of the associative strengths. Indeed, strongly associated words share more neurons with the activated word, so the time need for the network to reach their corresponding attractor when they are processed is shorter, which correspond to higher level of activation.

(ii) Inhibitory effects can be accounted by DM, given that a non associated prime activates the corresponding attractor which does not include neurons coding for non-associated targets, and that a neutral pattern activates a random pattern in the network corresponding to no learned attractor and which can include some neurons coding for the target word. Then when processing the target word the network takes less time to reach the attractor from a random pattern of activation (including neurons of the target) than from the attractor of a non-associated prime (not including any neuron of the target).

(iii) Cancelled priming effects by a non associated interposed word are also accounted by DM models given that the processing of the non-associated interposed word will activate a new attractor in the network replacing the attractor of the prime. Then neurons coding for a target associated to the prime but not to the interposed word would be no longer activated, which correspond to cancelled priming effects.

However, the DM models predict cancelled priming effects as soon as the interposed word is processed, which is contradictory with experimental data reporting priming effects at short SOA whatever the association of the interposed word (Balota & Paul, 1996; Lavigne & Vitu, 1997; Lavigne et al., submitted; McNamara, 1994).

Furthermore, DM models account for priming effects through shared neurons between attractors. This coding in memory is based only on semantic features shared by word meanings, and not on the temporal organization of words (events) occurring in the environment.

3.2 Anticipatory Attractor Neural Networks (Anticipatory Models)[1]

A model of anticipatory semantic processes must be able to code in memory internal representations of dynamic sequences of events. The model must then perform a spatial associative coding in memory of temporal sequences in the environment (Amit et al., 1994, Brunel, 1994, 1996). In this anticipatory attractor neural networks, word meanings are coded as patterns of activation across a subset of the entire network (attractor), and associations are made between attractors coding for words occurring frequently in temporal sequences.

The network developed is composed of many interconnected neurons. Neurons are divided in two groups: excitatory neurons that code for stored words; and inhibitory neurons that regulate the overall activity in the network and avoid runaway excitation. Neurons receive several types of inputs: (i) feedback from other excitatory neurons; (ii)

[1] We are grateful to Nicolas Brunel for his comments on how his model can account for anticipatory semantic processing.

feedback from inhibitory cells; (iii) background external inputs; and (iv) specific external inputs during word presentation. Each neuron i sums its inputs:

$$I_i = Ii_{(ext)} + \tau \Sigma v_{j (E)} w_{ij(E)} - \tau \Sigma v_{j (I)} w_{ij(I)}$$

where where I_i represents the amount of activation directed to the neuron i, $Ii_{(ext)}$ represents background external input, $w_{ij(E)}$ and $w_{ij(I)}$ represent the synaptic weights between neurons i and respectively activatory and inhibitory neurons j, $v_{j (E)}$ and $v_{j (E)}$ represent the spike rates of respectively activatory and inhibitory neurons j, and τ is the integration time constant.

Each neuron produces an output via a sigmoid response function. A simple dynamics can be via a first-order differential equation:

$$\tau \, d\eta /dt = -\eta + \Phi(I)$$

where τ is the neuron time constant, η the output rate, and I the synaptic input (see Amit & Brunel, 1996; Brunel, 1996).

During the learning stage each word is represented in the network by the activation of a subset of cells (chosen in an uncorrelated way from word to word) during presentation of the word. Connections between excitatory neurons store the words and the associations between them. Indeed, the delayed activities of the neurons in the model allow associative learning not only between neuron coding for a same word pattern (i. e. correlated at a given time), but also between neuron coding for word patterns presented in sequences (i. e. correlated in time as successive events). This can be achieved by an unsupervised learning mechanism such as a Hebb-like rule associating neurons coding for successive words (Brunel, 1996). Due to the pattern of excitatory connections, and if background external inputs and balance between inhibitory and excitatory inputs are chosen accordingly, the network has a number of fixed point attractors: (i) One non specific, spontaneous activity attractor, reached when something else than a word is shown to the network (e. g., a neutral stimulus). In this state, all cells fire at some low spontaneous activity, which stays low due to inhibitory feedback. (ii) Many specific attractors, each of them corresponding to individual words. These are reached after a word is shown to the network.

In absence of priming effects and association learning, the pattern of activation of the network in one of the attractors (isolated word) would be: (i) cells coding for the word: active at a higher level than spontaneous activity; (ii) all other cells: active at slightly lower levels than spontaneous activity.

With association learning, the attractors are modified. Attractors coding for temporaly correlated words (prime and associated target) are associated in the network. Then the pattern of activation in the attractors coding for a perceived prime become: (i) cells coding for the prime word are active at a higher level than spontaneous activity; (ii) cells coding for associated target words are active at an intermediate level (between high level and spontaneous activity) (iii) all other cells are active at lower levels than spontaneous activity. The resulting effect is to have (spatial) correlations between attractors corresponding to associated words. Then, when a context word is presented to the network, an associated target is preactivated in the network before being actually perceived by the network, corresponding to semantic anticipatory processes. This main property of the network allow to modelize other experimental data on anticipatory semantic processes:

(i) Dealing with activation processes:

The basic data of activatory semantic priming (that RT is shorter for associated than for non-associated target words) follows directly from this framework. Indeed, when a prime word is shown (e.g., ‘neuron’, the network goes in the corresponding attractor. Thus, cells coding for associated targets words (‘brain’) are active at an intermediate level. Cells coding for non-associated words have a lower than spontaneous activity level. Then, when ‘brain’ is presented to the network, the corresponding cells start to be activated from a higher level than spontaneous activity. It means that the attractor corresponding to associated words will be reached faster, and therefore the reaction times will be smaller than if the first word had not been presented previously. On the other hand, if a non-associated word is shown (e. g., ‘window’), cells start with a lower than spontaneous activity level, and thus the reaction time will be longer.

The activation process in the network also increases with time. Experimental data report that a prime weakly activates an associated target at short time delays, the activation increasing with time. In cases when the neuronal dynamics of convergence of the network to an attractor are slow enough, neurons coding for the prime and target are activated above the threshold when the prime is presented to the network (Activation process). In the model the neurons coding for the prime activate neurons coding for associated targets. This activation is rapid though not being maximum at short delays, and reach a maximum after a time delay.

Activation is proportional to the strength of association, leading to stronger activatory effects on strongly associated targets than on weakly associated targets. The more neurons coding the prime and neurons coding the target are associated, the more neurons coding the target are activated above the level of spontaneous activity when the prime is presented to the network.

Activation is sustained through time. At long time delays neurons of the attractor corresponding to the prime and associated target are strongly activated (up to a maximum) as long as a new word pattern is presented to the network. Then the activation of the target can be sustained at long delays in the absence of interposed interfering word.

The processing of sequences of associated word (prime and interposed word) does not change the activation of target associated to both words (see the interposition section for cases of non-associated interposed word).

(ii) Dealing with inhibition processes:

Experimental data report a possibility for targets to be inhibited by a non-associated prime compared to a neutral prime. In the model a neutral pattern can introduce diffuse activation in the network, same as the spontaneous activity, neither activating nor inhibiting any pattern in memory. On the other hand, a non-associated prime direct the network to an attractor corresponding to the prime and its associated targets, but not to non-associated targets. A non-associated target is then coded by neurons which are activated below the level of spontaneous activity. This increases time to reach the attractor of the non-associated targets when the word is presented compared to cases when the network is in a state of spontaneous activity.

Inhibition processes are reported to be slow. When the prime is presented to the network, neurons coding for the prime and associated targets are progressively activated above threshold (Activation process). The neurons coding for non-associated targets are progressively inhibited at a rate corresponding to the dynamic of the network (by the inhibitory neurons), being less activated than the spontaneous activity only at long SOAs. Then at long delays inhibitory effects can occur compared to the spontaneous activity involved by a neutral prime.

Nota: Inhibition depends on the effect of the 'neutral' prime baseline: non-associated target is inhibited compared to spontaneous activity; but is not inhibited compared to null activity (if the neutral prime does not activate any word-like pattern of neurons in the network).

(iii) Dealing with interposition-based inhibitory processes:

Experimental data report slow inhibition processes when a non-associated word is interposed between associated prime and target. Then the target is inhibited by the interposed word at long SOAs only. Still according to slow neuronal dynamics, neurons coding for the prime and target are activated above threshold when the prime is presented to the network (Activation process). A non-associated interposed word presented after the prime would progressively diminish the activation of the neurons coding for the prime and target. At short delays, the neurons coding for the prime and target would be less activated due to a beginning of inhibition by inhibitory neurons. But they would still be activated above spontaneous activity at short delays. Then if the target (associated to the prime) is presented just after the non-associated interposed word, the network has not time to completely inhibit the target which is still activated by the prime. At longer delays however, the target is presented later after processing of the interposed word. Then the network has time to inhibit the target which is not activated anymore. It is a case of cancelled activation which would correspond to interposition-based inhibitory effects.

This type of attractor neural network accounts for both rapid activatory and slow inhibitory anticipatory semantic processes. More simulations testing specific parameters for slow convergence dynamics are still necessary to precisely compare the time delays used in the experiments and the ones necessary to the network. However this type of model appear to be a good candidate for a simulation of further anticipatory semantic processes reported in experimental studies, as well as a good way to modelize anticipations and selection of anticipation in memory in relation to incursion and hyperincursion processes (Dubois, 1996).

4 Adapted Anticipations and Faithfull Perceptions

Adaptation to a changing environment implies a double constraint of adapted anticipations and veridical perceptions. Semantic anticipations can be confirmed or not by actually perceived events, leading to speeded perceptive processes and behavioral responses if confirmed, and needing slow faithful representation if not confirmed. To increase cases when anticipations are confirmed (their adaptive value), anticipatory processes must take into account not only of a single contextual event, but of sequences of events.

Though anticipatory processes would be quite straightforward in a simple environment, such as a single perceived event (a prime word), one must define more elaborated anticipatory processes when sequential context is processed, involving at least two different perceived patterns (a prime word and an interposed word). In changing environment in which patterns are perceived/behaved in sequences, anticipations have to constantly adapt to on-line changes in the environment, predicted or not from the anticipatory system. In this case a given pattern in the environment can trigger sequences of anticipations (of possible events to occur), which can be confirmed or not by a subsequent perceived event. Following the differential anticipations made as a function of the sequence of perceived patterns, anticipatory selection processes in memory would have to involve different types of cognitive anticipatory processes; such as:

(i) From the perception of a first event (prime word) in the environment: Perceptive activation of the corresponding pattern in memory and anticipatory activation of associated patterns.

(iia) From the perception of a second event anticipated in memory: Pursuit of the anticipatory activation in memory of the same previously anticipated patterns.

(iib) From the perception of a second event not anticipated in memory: A slow shift in the anticipations, due to inhibition of previous anticipations and activation of new ones. This shift is slow and allow anticipation to either (i) resist (no shift) to local and short interfering events, or (ii) to adapt (shift) to new anticipations based on the new perceived event.

Perceptive processing of an event which is not anticipated in memory would not be enhanced nor biased by anticipations. Its meaning would not be biased as a function of the context and would be fully accessed. When anticipations fail to predict an upcoming event, perceptive processes would then allow faithful access to the whole meaning of the perceived event. The balance between anticipatory and perceptive processes would then determine the adaptation of the system to previous events or new events in the environment.

The amount of time given to anticipations from a previous event and perception of a new event would determine the respective times allowed to anticipations or perception, to sustain previous anticipations or to shift them for new anticipations. Indeed, processing time allowed to a prime word influence the activatory effect on an associated target in memory (Lorch, 1982; Ratcliff & McKoon, 1981). Then when processing sequences of events, the variable amounts of time allowed to the different events would then determine their processing time in the sequence, and then their ability to trigger new anticipations and change previous ones or not. Processing time would then correspond to attention given to different anticipations triggered in parallel from different events, and would determine the selection among the set of anticipations.

5 Conclusion

Anticipation is an important cognitive ability of animal and human brains, which need internal cognitive representations of both the environments in which to anticipate and the behaviors adapted to these environments. With regard to the way in which a given system can adaptively interact with its environment, the advantage of anticipatory processes concerns perception speed and performance and selection of adapted behavior. Anticipations appear to be fundamental processes in memory allowing survival, which would correspond to a semantic of life involving not only internal semantic representations, but dynamical adapted interactions between a perceived environment and a living system.

Anticipatory attractor neural networks are good models of semantic anticipatory processes. Further developments would have to simulate to which extent processing time of events in the environment can account for the selection among parallel anticipations in memory. This would allow to define properties of attentional processes in terms of network dynamics and to test the model for its ability to account for both semantic and attentionnal anticipatory processes.

Because anticipations are important cognitive processes for living systems to survive in complex environments, they are important for cognitive science to study in both experimental and modeling ways.

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References

Amit, D. J. (1989). Modeling Brain Function: The world of attractor neural networks. Cambridge University Press.

Amit, D. J., Brunel, N., & Tsodyks, M. V. (1994). Correlations of hebbian cortical reverberations: Experiment vs. theory. Journal of Neurosciences, 14, 6635.

Anderson, J. R. (1983). The architecture of cognition. Cambridge, MA: Harvard University Press.

Balota, D. A. (1983). Automatic semantic activation and episodic memory encoding. Journal of Verbal Learning and Verbal Behavior, 22, 88-104.

Balota, D. A., Black, S. R. & Cheney, M. (1992). Automatic and attentional priming in young and older adults: Reevaluation of the two-process model. Journal of Experimental Psychology: Human Perception and Performance, 18, 485-502.

Balota, D. A., Chumbley, J. I. (1984). Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision stage. Journal of Experimental Psychology: Human Perception and Performance, 10, 340-357.

Balota, D. A. & Paul, S. T. (1996). Summation of activation: Evidence from multiple primes that converge and diverge within semantic memory. Journal of Experimental Psychology: Learning, Memory and Cognition, 22, 4, 827-845.

Balota, D. A., Pollatsek, A. & Rayner, K. (1985). The interaction of contextual constraints and parafoveal visual information in reading. Cognitive Psychology, 17, 364-390.

Balota, D. & Rayner, K. (1983). Parafoveal visual information and semantic contextual constraints. Human Perception and Performance, 9, 726-738.

Balota, D. & Rayner, K. (1991). Word recognition processes in foveal and parafoveal vision: the range of influence of lexical variables. In D. Besner & G. Humphreys (Eds.), Basic processes in reading: Visual word recognition (pp. 198-232). Hillsdale, Hove, London: Lawrence Erlbaum.

Becker, C. A. (1979). Semantic context and word frequency effect in visual word recognition. Journal of Experimental Psychology: Human Perception and Performance, 5, 252-259.

Becker, C. A. (1980). Semantic context effects in visual word recognition: An analysis of semantic strategies. Memory & Cognition, 8, 493-512.

Becker, C. A. (1985). What do we really know about semantic context effects during reading ? In D. Besner, T. G. Waller, & E. M. MacKinnon (Eds.), Reading research: Advances in theory and practice, vol. 5 (pp 125-166). Toronto: Academic Press.

Becker, C. A. & Killion, T. H. 1977. Interaction of visual and cognitive effects in word recognition. Journal of Experimental Psychology: Human Perception and Performance, 3, 389-401.

Berthoz, A. (1996). Les sens du mouvement. Paris, Odile Jacob.

Brodeur, D. A. & Lupker, S. J. (1994). Investigating the effects of multiple primes: An analysis of theoretical mechanisms. Psychological Research, 57, 1-14.

Brunel, N. (1996). Hebbian learning of context in recurrent neural networks. Neural Computation, 8, 1677-1710.

Brunel, N. (1994). Dynamics of an attractor neural network converting temporal into spatial correlations. Network, 5, 449.

Carr, T. H., McCauley, C., Sperber, R. D. & Parmelee, C. M. (1982). Words, pictures, and priming: On semantic activation, conscious identification, and the automaticity of information processing. Journal of Experimental Psychology: Human Perception and Performance, 8, 757-777.

Cheesman, J. & Merikle, P. M. (1984). Priming with and without awareness. Perception and Psychophysics, 36, 387-395.

Collins, A. M. & Loftus, E. F. (1975). A Spreading Activation Theory of Semantic Processing. Psychological Review, 82, 407-28.

Collins, A. M. & Quillian, M.R. (1969). Retrieval Time from Semantic Memory. Journal of Verbal Learning and Verbal Behaviour, 8, 240-247.

Conrad, C. 1972. Cognitive economy in semantic memory. Journal of Experimental Psychology, 92, 149-154.

Cornilleau-Perez, V. & Droulez, J. (1993). Stereo-Motion Cooperation and the Use of Motion Disparity in the Visual Perception of 3-D Structure. Perception & psychophysics, 54, 223 .

Cruz, C. (1992). Knowledge-representation networks: Goal direction in intelligent neural systems. In Levine, D. S. & Leven, S. J. (Eds), Motivation, emotion and goal direction in neural networks (pp 369-410), Lawrence Erlbaum Associates, Hillsdale, N.J.

de Groot, A. M. (1984). Primed lexical decision: Combined effects of the proportion of related prime-target pairs and the stimulus-onset asynchrony of prime and target. Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 36A, 253-280

den Heyer, K., Briand, K. & Smith, L. (1985). Automatic and strategic factors in semantic priming: An examination of Becker’s model. Memory and cognition, 13, 228-232.

Dubois, D. M. (1996). Hyperincursive stack memory in chaotic automata. In A. C. Ehresman, G. L. Farre & J.-P. Vanbremeersh (Eds.): Proceedings of the ECHOS Symposium, 77-82. Amiens – France, Université de Picardie Jules vernes.

Dubois, D. M. (1998a). Introduction to computing anticipatory systems. International Journal of Computing Anticipatory systems, 2, 3-14. D. Dubois (Ed.), CHAOS (Publisher).

Dubois, D. M. (1998b). Computing anticipatory systems with incursion and hyperincursion. Computing Anticipatory Systems: CASYS – first international conference, D. Dubois (Ed.), American Institute of Physics (Publisher), AIP conference proceedings 437, 3-29.

Dubois, D. & Sprenger-Charolles, L. (1988). Perception / Interprétation du langage écrit: Contexte et identification des mots au cours de la lecture. Intellectica, 5, 113-146.

Duffy, S. A., Henderson, J. M. & Morris, R. K. (1989). Semantic facilitation of lexical access in semantic during sentence processing. Journal of Experimental Psychology: Learning, Memory, and Cognition, 15, 791-801.

Ehrlich, S. F. & Rayner, K. (1981). Contextual effects on word perception and eye movements during reading. Journal of Verbal Learning and Verbal Behavior, 20, 641-655.

Everatt, J. & Underwood, G. (1992). Parafoveal guidance and priming effects during reading: A special case of the mind being ahead of the eyes. Consciousness & Cognition, 1, 186-197.

Favreau, M. & Segalowitz, N. S. (1983). Automatic and controlled processes in the first- and second-language reading of fluent bilinguals. Memory and Cognition, 11, 565-574.

Fischler, I. & Goodman, G. O. (1978). Latency of associative activation in memory. Journal of Experimental Psychology: Human Perception and Performance, 4, 455-470.

Fodor, J. A. (1983). The modularity of mind, essay on faculty psychology. MIT Press.

Forster, K. I. (1981). Priming and the effects of sentence and lexical contexts on naming time: evidence for autonomous lexical processing. Quarterly Journal of Experimental Psychology, 33A, 465-495.

Foss, D. J. (1982). A discourse on semantic priming. Cognitive Psychology, 14, 590-607.

Fowler, C. A., Wolford, G., Slade, R. & Tassinary, L. 1981. Lexical access with and without awareness. Journal of Experimental Psychology: General, 110, 341-362.

Freedman, J. L. & Loftus, E. F. (1971). Retrieval of words from long term memory. Journal of Verbal Learning and Verbal Behavior, 10, 107-115.

Fuentes, L. J., Carmona, E., Agis, I. F. & Catena, A. (1994). The role of the anterior attention system in semantic processing of both foveal and parafoveal words. Journal of Cognitive Neuroscience, 6, 17-25.

Fuentes, L. J. & Ortells, J. J. (1993). Facilitation and interference effects in a Stroop-like task: Evidence in favor of semantic processing of parafoveally-presented stimuli. Acta Psychologica, 84, 213-229.

Fuentes, L. J. & Tudela, P. (1992). Semantic processing of foveally and parafoveally presented words in a lexical decision task. Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 45, 299-322.

Gillund, G. & Shiffrin, R. M. (1984). A retrieval model for both recognition and recall. Psychological Review, 91, 1-67.

Glenberg, A. M. (1997). What memory is for, Behavioral and Brain Sciences, 20 (1), 1-55.

Goodman, K. S. (1976). Reading: A psycholinguistic guessing game. In H. Singer & R.B. Ruddell (Eds.), Theoretical models and processes of reading (pp. 129-134). Newark: International Reading Association. pp. 497-508.

Greenwald, A. G., Draine, S. C. & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. Science, 273, 1699-1702.

Gossberg, S., Levine, D. S. & Schmajuk, N. (1992). Associative learning and selective forgetting in a neural network regulated by reinforcement and attentive feedback. In Levine, D. S. & Leven, S. J. (Eds), Motivation, emotion and goal direction in neural networks (pp 37-62), Lawrence Erlbaum Associates, Hillsdale, N.J.

Haber, R. N. (1976). Control of eye movements in reading. In R.A. Monty, & J. W. Senders (Eds.), Eye movements and Psychological Processes (pp. 443-451). Hillsdale, NJ: Erlbaum.

Hines, D., Czerwinski, M., Sawyer, P. K. & Dwyer, M. (1986). Automatic semantic priming: Effect of category exemplar level and word association level. Journal of Experimental Psychology: Human Perception and Performance, 12, 370-379.

Hinton, G. E. & Shallice, T. (1991). Lesioning an Attractor Network: Investigations of Acquired Dyslexia. Psychological review, 98, 74.

Hopfield, J. J. (1982). Neural networks and physical systems with emergent collective computational abilities. Proceedings of National Academy of Science, 79, 2554-2558.

Hopfield, J. J. & Tank, D. W. (1986). Computing with neural circuits: A model. Science, 233, 625-633.

Hochberg, J. (1970). Components of literacy: Speculation and exploratory research. In H. Levin, & J. P. Williams (Eds.), Basic studies on reading (pp. 74-89). New York: Basic Books.

Hochberg, J. (1975). On the control of saccades in reading. Vision-Research, 15.

Hochberg, J. (1976). Toward a speech-plan eye movement model of reading. In R. A. Monty & J. W. Senders (Ed.), Eye movements and psychological processes (pp. 397-416). Hillsdale, N. J. Erlbaum.

Hollender, D. (1986). Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: A survey and appraisal. Behavioral and Brain Sciences, 9, 1-66.

Hyönä, J. & Jarvella, R. J. (1994). Time course of context effects during reading: An eye fixation analysis. In G. d'Ydewalle & J. Van Rensbergen (Eds.), Perception and Cognition: Advances in eye movements research (pp. 239-249). Studies in visual information processing, vol. 4 (pp 239-249). Elsevier, Amsterdam, North Holland.

Keefe, D. E. & Neely, J. H. (1990). Semantic priming in the pronunciation task: The role of prospective prime-generated expectancies. Memory & Cognition, 18, 289-298.

Kintsch, W. (1988). The role of knowledge in discourse comprehension: a construction-integration model. Psychological Review, 95, 163-182.

Kowler, H (1990). The role of visual and cognitive processes in the control of eye movements, In E. Kowler (Ed.), Eye movements and their role in visual and cognitive processes (pp. 1-70). Elsevier Science Publishers BV (Biomedical Division).

Landauer, T. K., Foltz, P. W. & Laham, D. (1998). An introduction to latent semantic analysis. Discourse Processes, 25, 259-284.

Lavigne, F. & Dubois, D. (1999). Context effects and associative anaphora in reading, Journal of Pragmatics, 31, 399-415.

Lavigne, F. & Vitu, F. (1997). Time course of facilitatory and inhibitory semantic priming effects in visual word recognition. International Journal of Psycholinguistics, 13, 311-349.

Lavigne, F., Vitu, F & d'Ydewalle. (in press). Context effects and parafoveal preview in sentence reading, Acta Psychologica.

Lavigne, F., Vitu, F & d'Ydewalle. (submitted). Time-course of facilitatory and inhibitory context effects in sentence reading.

Levine, D. S., Leuven, S. J. & Prueitt, P. S. (1992). Integration, disintegration and the frontal lobes. In Levine, D. S. & Leven, S. J. (Eds), Motivation, emotion and goal direction in neural networks (pp 301-334), Lawrence Erlbaum Associates, Hillsdale, N.J.

Logan, G. D. (1988a). Automaticity, resources, and memory: Theoretical controversies and practical implications. Human-Factors, Special Issue: Human information processing: Theory and applications, 30(5), 583-598.

Logan, G. D. (1988b). Toward an instance theory of automatization. Psychological Review, 95(4), 492-527.

Lorch, 1982.

McClelland, J. L. & O'Regan, J. K. (1981). Expectations increase the benefit derived from parafoveal visual information in reading words aloud. Journal of Experimental Psychology: Human Perception and Performance, 7, 634-644.

Marcel, A. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. Cognitive Psychology, 15, 197-237.

Massaro, D. W., Jones, R. D., Lipscom, D. & Schols, R. (1978). Role of prior knowledge on naming and lexical decisions with good and poor stimulus information. Journal of Experimental Psychology: Human Learning and Memory, 4, 498-512.

Masson, M. E. J. (1991). A distributed memory model of context effects in word identification, In D. Besner and G. Humphreys (Eds.), Basic processes in reading: Visual word recognition (pp. 233-263) Hillsdale, Hove, London, Lawrence Erlbaum.

Masson, M. E. J. (1995). A distributed memory model of semantic priming. Journal of Experimental Psychology: Learning, Memory & Cognition, 21, 3-23.

McKoon, G. & Ratcliff, R. (1992). Spreading activation versus compound cue accounts of priming: Mediated priming revisited. Journal of Experimental Psychology: Learning, Memory, and Cognition, 18, 1155-1172.

McNamara, T. P. (1994). Theories of Priming: II. Types of primes. Journal of Experimental Psychology: Learning, Memory & Cognition, 3, 507-520.

Millis, M. L. and Button, S. B. (1989). The effect of polysemy on lexical decision time: Now you see it, now you don't. Memory and Cognition, 17, 141-147.

Meyer, D. E., Schvaneveldt, R. W. & Ruddy, M. G. (1975). Loci of contextual effects on visual word recognition. In P. M. A. Rabbitt & S. Dornic (Eds.), Attention and Performance V, New York, Academic Press.

Mobus, G. E. (1994). Toward a theory of learning and representing causal inferences in neural networks. In Levine, D. S. & Aparicio IV, M. (Eds.). Neural networks for knowledge representation and inference (pp 339-374). Lawrence Erlbaum Associates, Hillsdale, N. J.

Monsell, S. (1991). The nature and locus of word frequency effect in reading, In D. Besner and G. Humphreys (Eds.), Basic processes in reading: Visual word recognition (pp. 148-197). Hillsdale, Hove, London: Lawrence Erlbaum.

Neely, J.H. (1976). Semantic priming and retrieval from lexical memory: Evidence for facilitatory and inhibitory processes. Memory & Cognition, 4, 648-654.

Neely, J.H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. Journal of Experimental Psychology: General, 106, 226-254.

Neely, J.H. (1991). Semantic priming effects in visual word recognition: A selective review of currents findings and theories. In D. Besner & G. Humphreys (Eds.), Basic processes in reading: Visual word recognition (pp. 264-336). Hillsdale, Hove, London: Lawrence Erlbaum.

Neely, J.H. & Keefe, D.E. (1989). Semantic context effects on visual word processing: A hybrid prospective/retrospective processing theory. In G. H. Bower, (Ed.), The psychology of learning and motivation: Advances in research and theory, vol 24 (pp. 207-248). NewYork: Academic Press.

Neely, J.H., Keefe, D.E. & Ross, K. (1989). Semantic priming in the lexical decision task: Roles of prospective prime-generated expectancies and retrospective semantic matching. Journal of Experimental Psychology: Learning, Memory and Cognition, 15, 1003-1019.

Norris, D. (1986). Word recognition: Context effects without priming. Cognition, 22, 93-136.

Onifer, W. & Swinney, D. A. (1981). Accessing lexical ambiguities during sentence comprehension: Effects of frequency of meaning and contextual bias. Memory and Cognition, 9, 225-236.

O'Regan, J.K. (1990). Eye movements and reading. In E. Kowler (Ed.), Eye movements and their role in visual and cognitive processes (pp. 395-453). Elsevier Science Publishers BV (Biomedical Division).

O'Seaghdah, P. G. (1989). The dependence of lexical relatedness effects on syntactic connectedness. Journal of Experimental Psychology: Learning, Memory and Cognition, 15, 73-87.

Perlmutter, J., Sorce, P. & Myers, J. L. (1976). Retrieval processes in recall. Cognitive Psychology, 8, 32-63.

Posner, M. J. & Snyder, C. R. R. (1975a). Facilitation and Inhibition in the processing of signals. In P. M. A. Rabitt & S. Dornic (Eds.), *Attention and performance V* (pp. 669-698). New York: Academic Press.

Posner, M. J. and Snyder, C. R. R. (1975b). Attention and cognitive control. In R. L. Solso (Ed.), Information processing and cognition: The Loyola Symposium (pp. 55-85), Hillsdale, NJ: Erlbaum.

Ratcliff, R. & Mc Koon, G. (1988). A retrieval theory of priming in memory, Psychological Review, 95, 385-408.
Ratcliff, R. & McKoon, G. (1994). Retrieving information from memory: Spreading activation theories versus compound-cue theories. Psychological Review, 101, 177-184.
Rayner, K. &. Balota, D.A. (1989). Parafoveal preview and lexical access during eye fixations in reading. In W. Marslen-Wilson (Ed.), Lexical representation and process (pp. 261-290). Hillsdale, Hove, London: Lawrence Erlbaum.
Rosen, R. (1985). Anticipatory Systems – Philosophical, Mathematical and Methodological Foundations. Pergamon Press.
Schwanenflugel, P. J. & LaCount, K. L. (1988). Semantic relatedness and the scope of facilitation for upcoming words in sentences. Journal of Experimental Psychology: Learning, Memory, and Cognition, 14, 344-354.
Schwanenflugel, P. J. & White, C. R. (1991). The influence of paragraph information on the processing of upcoming words. Reading Research Quarterly, 26, 160-177.
Sereno, S. C. & Rayner, K. (1992). Fast priming during eye fixations in reading. Journal of Experimental Psychology: Human Perception and Performance, 18, *1*73-184.
Sharkey, A. J. C. & Sharkey, N. E. 1992. Weak contextual constraints in text and word priming. Journal of Memory and Language, 31, 543-572.
Sheliga, B. M., Riggio, L. & Rizzolatti, G. (1994). Orienting of attention and eye movements. Experimental brain research, 98, 507.
Simpson, G. B., Peterson, R. R., Casteels, M. A. & Burgess, C. (1989). Journal of Experimental Psychology: Learning, Memory and Cognition, 15, 88-97.
Smith, L C., Briand, K., Klein, R. M. & den Heyer, K. (1987). On the generality of Becker's verification model. Canadian Journal of Psychology, *41*, 447-452.
Spence, D. P. & Kimberly, C. O. (1990). Lexical co-occurrence and association strength, Journal of Psycholinguistic Research, 19, 317-330.
Sperber, R. D., McCauley, C., Ragain, R. D. & Weil, C. M. (1979). Semantic priming effects on picture and word processing. Memory and Cognition, 7, 339-345.
Shuberth, R.E., & Eimas, P.D. (1977). Effects of context on the classification of words and non-words. Journal of Experimental Psychology: Human Perception and Performance, 3, 27-36.
Schuberth, R. E., Spoehr, K. T. & Lane, D. M. (1981). Effects of stimulus and contextual information on the lexical decision process. Memory & cognition, 9, 68-77.
Stanovich, K. E. & West, R. F. (1979). Mechanisms of sentence context effects in reading: Automatic activation and conscious attention. Memory and Cognition, 7, 77-85.
Stanovich, K. E. & West, R. F. (1983). The generalizability of context effects on word recognition: A reconsideration of the roles of parafoveal priming and sentence context. Memory and cognition, 11, 49-58.
Swinney, D. (1979) Lexical access during sentence comprehension: (Re)consideration of context effects. Journal of verbal Learning and verbal Behavior, 18(6),645-659.

Tabossi, P. (1988a). Effects of context on the immediate interpretation of unambiguous Nouns. Journal of Experimental Psychology: Learning, Memory and Cognition, 14, 153-162.

Tabossi, P. (1988b). Accessing lexical ambiguity in different types of sentential contexts. Journal of Memory and Language, 27, 324-340.

Tabossi, P. & Zardon, F. (1993). Processing ambiguous words in context. Journal of Memory and Language, 32, 359-372.

Thompson-Schill, S., Kurtz, K.J. & Gabrieli, J.D.E. (1998). Effects of semantic and associative relatedness on automatic priming, Journal of Memory and Language, 38, 440-458.

VanVoorhis, B.A., & Dark, V. (1995). Semantic matching, response mode, and response mapping as contributors to retroactive and proactive priming, Journal of Experimental Psychology: Learning, Memory and Cognition, 21, 4, 913-932.

Varela, F., Thompson, E. & Rosh, E. (1999). The embodied mind: Cognitive science and human experience, MIT Press: Boulder, Co.

Vitu, F. (1991). The influence of parafoveal preprocessing and linguistic context on the optimal landing position effect. Perception & Psychophysics, 50, 58-75.

Vitu, F., O'Regan, J. K., & Mittau, M. (1990). Optimal landing position in reading isolated words and continuous text. Perception and Psychophysics, 47, 583-600.