Basic Mechanisms of Learning and Forgetting in Natural and Artificial Systems (European Commission project: HPRN-CT-1999-00065)

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1a. Research Topic

Learning and forgetting underlie all intelligent and adaptive behaviour. A clearer understanding of HOW learning and forgetting occur in humans is critical for establishing effective educational strategies and appropriate medical treatments for memory loss due to ageing, trauma, etc. We will propose a highly interdisciplinary approach to elucidating certain mechanisms that underlie learning and forgetting in the hope of improving our understanding of how and why some information is retained and other information is lost. While there is a substantial amount of research describing learning and forgetting abilities across the range of human ages (e.g., Baddeley, 1995), there is relatively little systematic inter-disciplinary research into the underlying mechanisms of learning and forgetting.

This is a particularly acute issue in today's highly technological society in which individuals of all ages and from all walks of life are constantly bombarded with information from an ever-widening range of sources. It is increasingly important to develop effective methods for ensuring that critical information is retained. The methods of achieving this can only be developed once the basic mechanisms of learning and forgetting have been clearly elucidated.

The work in the present project will be carried out by five research teams deeply committed to cognitive science, the interdisciplinary study of intelligent behaviour in humans, animals and machines. This relatively young field explicitly recognises the importance of exchanges of information among the various disciplines focusing on understanding the mechanisms of cognition. It bridges across psychology, philosophy, mathematical modelling, artificial intelligence, information technology, and the neurosciences. The field of cognitive science is actively engaged in elucidating processes and mechanisms of cognition and, as such, is the ideal discipline for addressing the research agenda laid out below. Although a flourishing area of research in the USA, the field is currently under-represented in Europe (see section 8), where the tradition of inter-disciplinary research is considerably less developed than in the United States. One key objective of this project is to promote the training of young European researchers in the techniques of cognitive science, in general, and in cognitive neuroscience, in particular.

We propose to investigate the processes of learning and forgetting by marshalling evidence from four broad research methodologies, namely: (1) empirical research with infant and adult human subjects, (2) computer simulations, (3) non-intrusive neuro-imaging studies, and (4) formal information–theoretic analyses. With this goal in mind, four broad themes of research will be pursued:

1. What are the nature and mechanisms of learning in neural systems: Are there several distinct mechanisms of learning? Do these mechanisms involve the collaboration of different systems within the brain? If so, how do these regions/mechanisms co-operate? How can the study of neuropsychological disorders inform research on learning?
2. How do basic learning abilities actually develop throughout infancy and childhood? Does the developmental process effect the types of mechanisms that operate in adulthood? Studying the development of cognitive mechanisms constrains the class of mechanisms that could underlie adult abilities.
3. To what extent are changes in knowledge accompanied by conscious awareness? More generally, what function does conscious awareness serve in learning? How can we dissociate explicit and implicit influences on learning? What are the neural correlates of explicit and implicit learning?
4. To what extent can these mechanisms of learning (and forgetting) be described as optimal with respect to solving specific problems (e.g., maintaining specific information about particular instances vs. representing the features common to many exemplars). What can neural network theory and rational analysis tell us about the principles along which information processing need to be organised in order to acquire information in an optimal way?

In order to investigate the issues above, five partner groups from France, Belgium, and the UK will share and pool their skills, methods and knowledge, as well as the specific subject populations to which they have access.

1b. Project objectives

In general terms, the overarching objective of the present project is to explore the basic mechanisms of human learning and forgetting. We have chosen a level of analysis above the level of individual neurones and, at the same time, below the traditional level of symbols. This is the level for which distributed connectionist networks (Smolensky, 1988) were designed and are best suited. A major, but certainly not unique, focal point of the project will be what we have called "dual-memory connectionist models." These are computational models loosely patterned after the hippocampal-neocortical architecture of human brains. Two of the teams participating in this project have extensive experience working with these models. Other connectionist architectures, especially recurrent networks, will also be explored, in particular, in the context of implicit learning. But in all cases the goal of the project is to gain a better understanding of high-level cognitive processes by exploring, through simulation and mathematics. the sub-symbolic substrate — a connectionist substrate — from which they emerge. The predictions of these models will then be tested using standard psychophysical and state-of-the-art neuro-imaging techniques.

The specific objectives of this project, then, are: (1) understanding the mechanisms of dual-network models of memory, (2) exploring the implications of the a dual memory system for the understanding of early and late memory capacities, (3) understanding the mechanisms underlying implicit and explicit learning, and (4) formalising the basic mechanisms of learning and forgetting using information theoretic notions of optimal information gathering and storage. Each of these objectives is discussed below.

1. Understanding the mechanisms of dual memory network models

To overcome the problem of catastrophic interference in neural networks (i.e., when new information overwrites existing information in the network), McClelland, McNaughton & O'Reilly (1995) have proposed that information is shunted back and forth between the hippocampus and the cortical regions during learning. This process has been operationalised in dual-memory network models (French, 1997; Ans & Rousset, 1997; Robins, 1996; Robins & McCallum, 1999).

We propose to explore the behaviour of these models by manipulating components of memory storage and information transfer mechanisms. The following simulations will be done: (1) Modifying the type of activation patterns used to shunt information between the memory stores, (2) Formally evaluating the information content of the stored representations (compared to the original input information), (3) Characterising the data compression that occurs during memory storage (4) Exploring the effect of interrupting various channels of flow on memory storage and retrieval, (5) Exploring the effect of different learning mechanisms and learning rates in the different memory stores, (6) Exploring the gradual coming on line of the dual system, (7) Exploring the accessibility of representations in each memory store. This latter experiment is of direct relevance to the issue of implicit vs. explicit memory stores.

2. Implications of dual memory model for early and late memory

Although interference effects are relatively rare in adults, they are far more common in early infancy (Mareschal & French, in press, Rovee-Collier, 1998). But why does this interference gradually disappear during development? One possibility is that a single memory system (which provides a good account of interference effects in infants) memory gradually becomes a dual-memory system, with the development of information flow between hippocampus and neocortex. A combination of dual memory connectionist modelling and high density Evoked Response Potential (HD-ERP) and behavioural studies will investigate this hypothesis.

Categorisation and memory are deeply intertwined. The basic function of categorisation is to relieve the load on memory. An important outstanding question is how infants develop more global categories. One reason infants may not initially form global categories is that there is simply *too much* variability between exemplars of different basic categories and the dual-memory model has been show to automatically decrease the variability of internally coded categories. If this decrease in internal variability does, in fact, occur, this will provide a truly novel explanation of category acquisition in infancy that can be directly related to basic neural information processing.

The information transfer between the two systems of a dual-memory model (something which could occur during REM sleep) has been shown to lead to gradual compression of internal representations and we will test this through functional Magnetic Resonance Imaging (fMRI) studies. If this representation compression is verified experimentally, this would constitute a major breakthrough because it would support a novel explanation of category-specific deficits in certain types of aphasia (see French & Mareschal, 1998) Finally, computational experiments involving lesioning the flow of information between the two memory components may provide alternative accounts of anterograde and retrograde amnesia.

3. Implicit vs. Explicit Learning

All learning has both implicit and explicit effects, in that it produces changes not only in the representations that are currently the focus of attention (e.g., a word that is memorised), but also produces changes in other, associated representations (e.g. semantically related words). These latter changes may not be available to conscious awareness and, in this case, they are best described as the indirect (or implicit) effects of the learning episode. This perspective on learning is only possible for systems that rely on distributed representations, such as connectionist networks. Low-level representations are conceived of as attractors in a multidimensional space in which any local change in the attractor landscape will automatically have non-local effects, causing reshaping of many other attractors in that space. Such indirect modifications are what we (Cleermans, 1998) believe should be described as "implicit learning".

We will test these ideas with adults by developing experimental paradigms inspired from research on perceptual learning and priming, Our interest will be to gather evidence that shows how: (1) experiences that are not considered by participants as producing learning can nevertheless have durable effects on processing, and (2) experiences that are considered by participants as producing learning along one dimension also influence performance along other dimensions. In addition to purely psychological testing, we will study the structure and the location of neural representations of implicit knowledge by means of fMRI. We will attempt to determine if there is flow of information from the hippocampus to neocortical regions during the transfer from implicit to explicit learning. Extensive connectionist modelling will be carried out to in parallel with the empirical research. The starting points in this development will no doubt be the attractor networks developed by Mathis & Mozer, the Elman network (1990), and the cascade-correlation algorithm introduced by Falhman (1988).

4. Information Theoretic analyses

According to the “simplicity principle”, learning involves searching for patterns from past experience. It also assumes that cognitive systems prefer patterns for which they can form concise encodings. Chater (1996) shows a direct connection between simplicity principles and Bayesian updating. Learning schemes based on simplicity have been widely studied in statistics (Rissanen, 1989) and artificial intelligence (Quinlan & Rivest, 1989); but they have been little explored as potential cognitive models of human learning. These theoretical tools provide the basis for building models of human learning in specific, well-understood, domains, such as artificial grammar learning (e.g., Redington & Chater, 1996) where there are strong links with Cleeremans' internationally known research in this area. In previous work, researchers at Warwick have already begun building new formal and computational methods for both artificial grammar learning, as well as categorisation, based on a simplicity principle. These methods will be applied to the dual memory model to: (1) formalise the data compression and information gathering mechanisms of the system, and (2) to explore links between these mechanisms, Baysian learning, and the “simplicity principle”

Potential breakthroughs

Together these four strands of research offer the possibility of substantial progress in the understanding of the foundations of learning and forgetting. By the end of this project, we will have achieved a greater detailed understanding of the dynamics of the dual memory model. We will also have provided alternative (neurally inspired) accounts of early infant categorisation and memory. We will have explored a possible alternative account of retroactive and anterograde amnesia. We will have contributed a mechanistic account of how the transition from implicit to explicit knowledge can occur. Finally, we will have formalised how these mechanisms related to optimal data gathering approaches. This latter finding will inform us as to how to present information to such a system so that it stores that information optimally.

Breakthroughs are also likely in existing lines of research. The first will involve determining whether the representational compression that has been observed in the dual-memory model actually exists in the human brain. If it does, this will pave the way for more important research into the origins of category-specific deficits in humans as discussed in French and Mareschal (1998). Finally, the application of connectionist models to infant category learning already has had considerable impact and can be expect to continue to do so as we explore the effect of the gradual coming on-line of the pseudopattern transfer mechanism between hippocampus and neocortex.

2. Scientific originality

Like all complex psychological issues, the question of learning and forgetting has been tackled on many fronts. We first review current understanding along each front. We then identify unanswered questions and show how the combination of approaches we present promises to lead to substantial achievements in the understanding of the mechanisms of learning and forgetting.

Dual-memory models and catastrophic interference in memory

Catastrophic interference occurs when learning new information completely erases previously learned information and is a serious problem for connectionist networks (McCloskey & Cohen, 1989; Ratcliff, 1990). Adults, however, do not experience catastrophic forgetting. McClelland, McNaughton & O'Reilly (1995) have suggested that the reason for this is the existence in the brain of two distinct, continually interacting processing areas, one for newly learned information (the hippocampus) and the other for long-term storage of that information (the neocortex). Dual network connectionist architectures have been developed (French, 1997; Ans & Rousset, 1997) that effectively overcome catastrophic interference. Information is continually passed between the separate areas of these models by means of pseudopatterns (Robins, 1995). (See "Research Method" below for more details.) It has been suggested (Robins, 1996; Robins & McCallum, 1999) that consolidation of information in the neocortex may occur by means of pseudopatterns generated during REM sleep. Representational compression has been observed in the model as a by-product of pseudopattern information-passing (French, 1997). One important question is whether this representational compression, which could explain various category-specific losses, actually occurs in the brain. We have designed experiments to test this at the University of Grenoble with fMRI technology.

The dual-network memory model provides a means of studying a wide range of phenomena related to normal and pathological forgetting. In preliminary simulations using the dual-memory model, French & Mareschal (1998) showed how this system, when lesioned, could account for category-specific semantic deficits found in some neuropsychological patients (e.g., Warrington and Shallice, 1984; Farah, Meyer, & McMullen, 1996; Hillis & Caramazza, 1991, Sacchett & Humphreys, 1992). Early models had assumed a dissociation between the representation of functional and perceptual features in the brain (Farah & McClelland, 1991).

Further, it is hoped that exploring the pseudopattern mechanism of information transfer between the two storage areas will lead to insights about anterograde and retrograde amnesia. The hypothesis to be tested is whether disruption of this information transfer mechanism alone, without actual lesioning of either memory area, can lead to the observed amnesiac effects.

Mechanisms of early learning and forgetting

New-borns can remember visually presented information over long retention intervals (Slater, 1995) Although infants clearly show long-term retention of visual stimuli, under some conditions the presentation of intervening material during the retention interval leads to catastrophic interference with the original material completely eradicated (e.g., Cohen & Gelber, 1975; Deloache, 1976; McCall, Kennedy, & Dodds, 1978). Interference effects decrease with age but continue well into later infancy (Rovee-Collier & Boller, 1995).

Very young infants can also be shown to separate complex visually presented stimuli into distinct categories (Quinn & Eimas, 1996). Categorisation is a means of reducing the load on memory (Rosch, 1975). Most studies of infant categorisation have relied on visually presented material (e.g., photographs). There is now ample evidence that young infants can form categorical representations of shapes, animals, furniture, and faces (Quinn and Eimas, 1996, or Hayne, 1996 for recent reviews). While there have been many studies describing infant categorisation competence at various ages, there have been few mechanistic accounts of how the underlying categorical representations emerge within a short-term testing session characteristic of many published categorisation studies. A common set of connectionist mechanisms underlying performance on different tasks has already been successfully proposed to explain the causes of the exclusivity asymmetry mentioned above and the elusive catastrophic interference effect in infant memory studies (Mareschal & French, 1997; Mareschal, French, & Quinn, submitted).

Mechanisms of Implicit and Explicit Learning

Experience constantly shapes memory, and memory, in turn, continuously influences further processing. However, the role of explicit awareness in learning is currently very controversial. Some authors defend the idea that learning tends to be systematically accompanied by awareness (e.g., Shanks & St. John, 1994; Perruchet & Vinter, in press; O'Brien & Opie, in press), while others defend the idea that learning can be unconscious, or at least implicit (e.g., Cleeremans et al., 1998; Reber, 1993; Berry and Dienes, 1993).

Any learning has both implicit and explicit effects, in the sense that learning will not only produce changes in the representations that are currently being attended to, but will also produce changes in other, associated representations. These latter changes may or may not become available to conscious awareness. When they are not, such changes are best described as the implicit, or indirect effects of the learning episode. The research teams in Brussels (Cleeremans, 1993) and Warwick (Redingote & Chater, 1997) are currently engaged in exploring the extent to which Elman-like networks (Elman, 1990) can capture performance in direct vs. indirect tasks in the context of the process-dissociation procedure (Jacoby, 1991). The dual network memory model also offers a tool for exploring the complex interactions between two memory stores (cf. the representations developed by implicit and explicit learning).

Information theory and its relation to learning and forgetting

Simplicity principles (Chater, 1999) have a long tradition in perception, going back to Mach and the Gestalt psychologists. Chater (1996) has shown how these principles can be formulated in a rigorous way using the machinery of Kolmogorov complexity theory (Li & Vitanyi, 1997). In unpublished work, Chater has formal results on language learning from positive evidence, which appear to have potentially significant implications for "poverty of the stimulus" arguments in language acquisition, recently modelled with a constrained connectionist network (Regier, 1996). A further aspect of this research concerns providing a theoretical basis for the active search for information. With Mike Oaksford (University of Wales at Cardiff), Chater has applied Bayesian models of optimal data selection, to psychological reasoning problems, capturing a wide range of previously baffling empirical regularities (Oaksford & Chater, 1994, 1996, 1998).

Advancing the state of the art

The dual-network model provides a neurally inspired mechanistic model of learning and forgetting. It is the unifying structure of the present proposal. The fMRI team (University of Grenoble) has the potential of directly verifying predictions from the dual-memory model, as well as from the connectionist and information-theoretic models of the other groups. In particular, representational compression is predicted by the dual-memory model and we hope to be able to observe it in the brain. If it actually exists, this would go a long way in explaining a certain types of memory loss due to trauma and ageing. In addition, the fMRI work will provide clear neurological evidence for the changes predicted by Chater and Cleeremans during implicit learning.

Another significant contribution of this research is the exploration of the hippocampal-neocortical transfer mechanism. We suggest that anterograde and retrograde amnesia may be due to damage to the transfer mechanisms between hippocampus and neocortex, rather than to damage to either area.

This research should also be able to provide answers to two important questions concerning infant category formation – namely, (1) Does the progressive coming on-line of the dual-memory system explain decreasing susceptibility to interference in infant memory with development? and (2) Does it play a role in enabling infants to learn global categories? These questions will be addressed through a combination modelling, experimental behavioural studies, and HD-ERP studies.

The dual network model speaks equally to the implicit/explicit knowledge debate which suggests that there may be dual stores or formats of knowledge representations. The dual network model provides a means of testing the accessibility of knowledge in two systems with similar knowledge stored in different formats. Differences in accessibility can be mapped onto implicit and explicit knowledge. Finally, a formal, information theoretic understanding these systems is arguably one of the most important aspects of this collaborative project because it will provide precise information on the power and limits of the systems under consideration, and in particular, the dual-memory model.

3. Research Method

The development of connectionist models of human memory is, unquestionably, one of the major achievements of current research in psychology and neuropsychology. Connectionist models are computer models loosely based on neural information processing (Hertz, Krogh, & Palmer, 1991). A significant part of the research described in this project revolves around connectionist models of learning, in general, and one such model, in particular, the so-called dual-memory model (French, 1997; Ans & Rousset, 1997). All of the teams making up this project were chosen because of their wide interdisciplinary background and their expertise in connectionist modelling. The research methodology that is to be applied is a fundamentally interdisciplinary mixture of basic theoretical work, computer modelling, and psychophysical and neurophysical (i.e., neuro-imaging) evaluation of the predictions of the models. The work divides roughly into four different methodologies:

<u>Computational research exploring of the dual-memory model</u>

The dual-memory model relies crucially on information transfer by means of pseudopatterns (Robins, 1995). Pseudopatterns provide a way of retrieving information about what a connectionist network has learned. By “bombarding” the network with a random set of inputs and observing the associated outputs, we can get an approximate idea of the input-to-output mapping (the response function) learned by the network. (Specifically, a “pseudopattern” is a random input string and its associated output.) Pseudopatterns are the mechanism by which information is transferred between each of the networks comprising the dual-memory model. Robins (1996) and Robins & McCallum (1999), among others, have suggested that REM sleep may consist of the activation of neural pseudopatterns which serve to consolidate information in the neocortex. There are numerous ways of generating pseudopatterns to extract information from a network, but they are presently poorly understood. We will examine these different techniques on our respective simulations and observe how accurately they are able to reproduce the originally learned functions and how this accuracy varies with the type of function learned.

<u>Experimental research testing the dual-memory model</u>

Representational compression: This will be investigated by two sets of different experiments, one relying on techniques from experimental psychology, the other from fMRI. In the traditional experiments, subjects will learn high- and low-variability categories before sleeping. REM sleep will be disrupted and we will test the subjects’ differential recall of the categories. Also, in other experiments of this type, we will attempt to induce catastrophic interference and determine which of the two types of categories is subject to less loss. The fMRI experiments using the new 3 Tesla facility in Grenoble will involve learning and subsequent observation of neural images before and after REM sleep. We predict that there will be a compression (i.e., shrinking) of the size of the cortical representations after REM sleep.

Category-specific deficits: French & Mareschal (1998) have some promising preliminary results that seem to show that, if representation compression does occur in the brain in a way similar to that observed in the dual-memory model, then this could lead to a novel explanation for category-specific losses observed in anomia (e.g., the preferential loss of “natural kinds” compared to “artificial kinds” categories). However, only elementary kinds of lesions of the network’s were considered for a small network. We intend to build more complex and more neurally accurate dual-memory model and test it using various local and distributed lesioning schemes.

Retrograde and anterograde amnesia. We believe that these types of amnesia may be due not so much to a true loss of stored information but rather to an inability to transfer information from hippocampus to neocortex or vice-versa. Lesioning tests of the dual-network architecture should be able to induce these kinds of amnesia in the dual-memory network. Specifically, if the pseudopattern transfer mechanism from the “hippocampal” network to the “neocortical” network is interfered with, we predict that we should see effects in the model similar to anterograde amnesia accompanied by the retrograde memory loss gradient normally observed in amnesiac patients.

Learning in infants Infant testing will rely on visual preference techniques. These are by far the most commonly used methods in contemporary infancy research. They are based on the finding that infants direct more attention to novel or unfamiliar stimuli. The dependent measure is the duration of looking time to a test stimulus. In the habituation-dishabituation methodology, infants are shown a series of stimuli until their looking time (attention) diminishes below set criterion. A release from habituation (renewed attention) to a subsequent test stimulus is interpreted as evidence that the infants have noticed a difference between the test stimulus and the familiarisation stimuli. In the paired preferential looking paradigm, infants are presented with familiarisation stimuli for a fixed duration. They are then presented with two test stimuli.

Preferential looking at the novel stimulus over and above looking at the familiar test stimulus is interpreted as evidence that the infant has noticed the difference between the two stimuli.

High density-ERPs involve placing non-intrusive recording electrodes on the infants' scalp and measuring EEGs in response to visually presented stimuli. Infants wear a 64 electrode Geodesic sensor net (Tucker, 1993) geometrically distributed across the scalp surface. HD-ERPs provide the appropriate combination of spatial and temporal resolution for testing the hypotheses we wish to address. Traditional, ERPs offer good temporal but poor spatial resolution. However, sampling from 64 points (high density) and at every 4ms from the scalp surface provides a reasonable map of current flow. Although not as spatially precise as fMRI techniques, HD-ERPS allows the separation of independent sources in the signal space that would not otherwise be possible.

The Centre for Brain and Cognitive Development (Birkbeck College) has received full ethical approval for HD-ERP and behavioural studies with infants from Medical Research Council (UK).

<u>Development and testing recurrent connectionist models of implicit/explicit learning</u>

The ULB team is currently developing a comprehensive connectionist model of implicit and explicit influences on sequence learning. The model's central idea is to root the implicit/explicit distinction in the notion of quality of representation: Implicit knowledge involves weak and distributed representations that can only trigger responses when an external input is also present (i.e., priming). In contrast, explicit knowledge involves stronger and more distinctive representations that can trigger responses independently of the presence of an external stimulus. To test these assumptions, we focus on <u>sequence learning</u>, — a paradigm (1) that is widely considered to be one of the best paradigms with which to study implicit learning, (2) that has already been successfully adapted for use in the context of neuroimaging studies, and (3) with which the ULB team has extensive experience (see Cleeremans & McClelland, 1991, Cleeremans, Destrebecqz & Boyer, 1998). In a typical sequence learning task, people are asked to react to the appearance of one of several possible stimuli on a computer screen by pressing as fast as possible on the corresponding key. Unknown to them, the sequence of successive stimuli contains regularities. Typical results indicate significant reaction time savings compared to performance on random material, even though people report no awareness of the relevant regularities. To measure the extent to which conscious and unconscious processes are involved in such skill acquisition, we will use the process dissociation procedure proposed by Jacoby (1991). After training, participants will be asked to perform two direct tasks: An inclusion task, in which they will be asked to generate sequences of stimuli that are <u>similar</u> to the material they have learned, and an exclusion task, in which they will be asked to generate sequences of stimuli that are <u>as different as possible</u> from the training material. In the inclusion condition, correct responses may reflect both conscious and unconscious influences. In the exclusion condition, however, the generation of responses similar to the training material can only indicate that participants were unable to avoid their production, and thus such responses reflect an implicit influence of memory. Conscious and unconscious contributions to performance can be numerically estimated for each participant at various points during training, and correlated (1) with brain activation changes as measured by fMRI to identify the neural correlates of these processes, and (2) with the model's performance under identical training conditions.

<u>Elaboration of a formal information-theoretical framework</u>

The University of Warwick's essential methodological role in this project will be to determine to what extent the *simplicity principle* (Chater, 1996) can apply to cognitive models of human learning and, in particular, to the particular models of human learning that are under consideration here. Chater and Cleeremans share strong research interests in artificial grammar learning (e.g., Redington & Chater, 1996) and the goal will be to use existing formal mathematical tools (and to develop others) to explore the characteristics of such learning. Further, we hope to be able to use these tools to gain a formal mathematical understanding of pseudopattern transfer mechanisms in the dual-memory model. This work has been begun for very simple networks by Frean & Robins (1998) but, for the moment, the effectiveness of these mechanisms is poorly understood mathematically. Finally, work will be done by the Warwick team to formalise the idea of representational compression. For the moment, the there is no formal working definition of "representational compression." The intuitive notion that "fewer nodes are active and thus the representation is more compressed" is inadequate. In particular, in a connectionist network, one can argue that inactive nodes are as computationally important as active nodes. In short, a clear, formal definition of this phenomenon needs to be developed and this will be one of the roles of the mathematicians on the University of Warwick team.

4. Work Plan

(Note: UG=Grenoble, ULB= Free University of Brussels, ULg = University of Liège, BC = Birkbeck College, UW= University of Warwick)

The work plan has a theoretical to applied organisation. The work completed at the end of each year forms the basis of the following year's research agenda. Tasks are distributed among the different partners in line with their expertise. Our staffing policy will call for hiring for each of the university teams: one post-doctoral researcher and one doctoral student for three (UK) or four (France/Belgium) years, depending on the time necessary for the completion of a doctoral dissertation.
The overall work plan is summarised below.

<u>Summary of work plan</u>

1st year: Study basic mechanisms of the dual-memory model and implicit learning (theory and simulations).
2nd year: Applications of dual-memory model to: Infant categorisation, infant memory, retrograde and anterograde amnesia and memory consolidation
3rd year: Empirical tests of dual-memory model using neuro-imaging (infants and adults) for dual-memory model, behavioural tests for dual-memory model
4th year: Empirical tests of implicit/explicit distinction using neuro-imaging for sequential learning task for implicit learning, behavioural tests for implicit/explicit distinction, implicit vs. explicit concept knowledge in infants, dishabituation vs. manipulation.

<u>Detailed breakdown of the Work Plan</u>

<u>12th month</u> (theoretical development):
- Develop a better understanding of the pseudopattern information transfer mechanism in the dual memory model. Simulation studies of various pseudopattern generation techniques (ULg, UG)
- Exploring theoretical aspects of representational compression using simulations and mathematical modelling (ULg, UW)
- Develop a connectionist framework for implicit/explicit learning and forgetting (ULB/ULg)
- Study the role of input variability on representation construction in the dual-memory model (BC, ULg).

<u>24th month</u> (modelling development):
- Development of an approximate scale of perceptual category variability (ULg, BC)
- Development of a theory of retrograde and anterograde amnesia within the framework of a dual-network connectionist architecture. (UG)
- Expand model of category-specific anomia (BC, ULg)
- Develop dual-network framework of the development of infant learning and forgetting (ULg/BC/UW)
- Develop a model of neocortex consolidation following REM sleep (ULg, UG)
- Global level categorisation in infancy emerging as a product of representational compression in the dual-memory model.

<u>36th month</u> (empirical exploration for dual-memory model):
- Using visual preference methods, test predictions/validity of dual-memory model account of category variability with infants (BC)
- Using fMRI techniques, test prediction of the dual-memory model of the existence of representation compression in the neocortex (ULg, UG)
- Using ERP techniques, test the prediction of increased activation into the neocortex with increased age of infants (BC, ULg)
- Clinical tests of anterograde and retrograde amnesia patients of hypothesis that they suffer from failure of transfer mechanism rather than explicit representational decay (UG)
- Experimental testing to ascertain the effect of disruption of REM sleep on long-term memory retention and forgetting of categories of different variability (ULg, UG).

<u>48th month</u> (empirical exploration for implicit/explicit distinction)
- Using fMRI techniques, study activation differences in implicit and explicit sequence learning tasks (ULB, UG).
- Compare categorisation in infancy using visual preference paradigm (implicit learning) and object manipulation tasks (explicit learning) (BC).
- fMRI studies of the effects of interference on explicit and implicit memory representations in neocortex (ULB, UG).

The completion of each phase will provide measurable indicators of the progress of the project. By the midterm review, we expect to have completed the theoretical and simulation work and, thereafter, we will be in a position to begin writing up that work for publication.

As part of the training programme (see section 10), we institute a series of annual internal technical reports to be circulated among members of the project. These reports will provide an means of assessing the progress of each of the participants.

The following table outlines the people who will be hired for this project, as well as the number of person-months of all other researchers who will be participating in the project

Professional research effort on research project			
Participants	Young researchers to be financed by the contract (person-months) (a)	Researchers to be financed from other sources (person-months) (b)	Researchers likely to contribute to the project (number of individuals) (c)
1. Université de Liège	PhD student: 48 months post-doc: 12 months	28.8 (3 researchers)	1 senior scientist + 4 junior scientists
2. Université de Grenoble	PhD student: 48 months post-doc: 24 months	28.8 (4 researchers)	3 senior scientists + 3 junior scientists
3. Université Libre de Brussels	PhD student: 48 months post-doc: 12 months	31.2 (4 researchers)	1 senior scientist + 5 junior scientists
4. Birkbeck College	PhD student: 36 months post-doc: 24 months	28.8 (4 researchers)	3 senior scientists + 3 junior scientists
5. University of Warwick	PhD student: 48 months post-doc: 18 months	14.4 (3 researchers)	3 senior scientists + 2 junior scientists
Totals	**PhD students: 228 months** **Post-docs: 90 months**	**132 person-months**	**11 senior scientists +** **17 junior scientists**

For the details involving the percentage of time devoted to the project by researchers who are already part of the participants' labs, as specified in column (b), please refer to the Section 5, "Collective Expertise." In the final column (c), we have indicated the total number of researchers, including the doctoral students and post-doctoral researchers to be hired, who will be involved in the project..

5. Collective Expertise

University of Liège

The Quantitative Psychology and Cognitive Sciences unit at the University of Liège is, in some sense, the lynchpin of the present project. Robert French, the director of this unit and the co-ordinator of the present project, has published work ranging from foundational issues in cognitive modelling, models of bilingual memory, catastrophic interference in neural networks and artificial life. His dual-memory model (French, 1997) is of particular importance to the present project.

Expertise

French is a computer scientist who specialises in connectionist modelling of behaviour. In addition to a PhD in computer science, he has formal training in mathematics, psychology and philosophy. He developed a dual-storage connectionist memory model architecturally patterned after the hippocampal-neocortical separation in the brain (McClelland, McNaughton, & O'Reilly, 1995) that was designed to avoid catastrophic interference during learning. This model appears to be appropriate to study a wide range of cognitive phenomena and will serve as the basis of much of the work proposed in this project.

Linkage to other teams

The Liège team is directly linked to all of the other four other teams. The team in Grenoble simultaneously and independently developed a similar dual-memory model (Ans & Rousset, 1997), also to overcome catastrophic interference. (This, in fact, is one of the main reasons these two teams are currently collaborating.) French's model and Bernard & Ans' model are not identical, however, and one of the purposes of the proposed research is to explore differences in these two approaches. Over the past three years, French and Mareschal at Birkbeck College have established a particularly fruitful collaboration on a number of connectionist projects involving infant learning (Mareschal & French, 1997; Mareschal & French, 1999). Most recently, they suggested that the dual-memory model might provide insights into a perception-based explanation of category-specific anomia (French & Mareschal, 1998). This work, while preliminary, seems very promising, especially, if the existence in the cortex of the representational compression observed in our model can be experimentally verified (see Section 1b "Project Objectives"). The dual-memory model has also been used by the University of Grenoble team to generate a number of empirically testable hypotheses involving retrograde and anterograde amnesia. Finally, French and Cleeremans (at the Free University of Brussels) have published joint work on Elman networks and implicit learning. They are also currently co-editing a book on the subject of implicit learning, based on a workshop organised by French at the University of Liège in 1998. The information-theoretic work done by Chater at Warwick will bear, in part, on a formalisation of mechanisms

Key scientific staff:

Professor Robert French	35 %
Dr. Daniel Defays, Adjunct professor	5 %
Mr. Christophe Labiouse, ULg researcher	20 %

Significant recent publications

French, R. M. (1999). Catastrophic Forgetting in Connectionist Networks. *Trends in Cognitive Sciences, 3*(4), 128-135.

French, R. M. (1997). Pseudo-recurrent connectionist networks: An approach to the "sensitivity–stability" dilemma. *Connection Science, 9*(4), 353-379.

University of Grenoble (Université Pierre Mendes-France, Grenoble 2)

The Grenoble team presents two major inter-linked components, both essential for the success of the present project. The first group does neuropsychological modelling and the second, functional Magnetic Resonance Imagery (fMRI). Both of these groups, and in particular, the latter will provide a key empirical data for the confirmation of modelling hypotheses.

Expertise

The *Mental Function Modelling* component of the University of Grenoble team (Bernard Ans & Stéphane Rousset) is working in the complementary areas of memory studies and neural network modelling. Understanding human learning and memory constitutes the core of their work in cognitive psychology, neuropsychology and computer simulation. Their work benefits from a tight integration within the regional hospital structure. One particularly important contribution of this unit is its expertise in artificial neural network modelling. Their aims are not only the development of general functional architectures reflecting mechanisms of normal and pathological human memory, but also the development of new connectionist algorithms. This close link between formal and psychological modelling is at the root of the “dual network solution” jointly proposed by Bob French (ULg) and by the Grenoble team. This unit has extensive expertise in the development of human memory models of temporal sequence learning, learning of reading, reading impairments, face identification and general transfer processes (see recent publications in *Psychological Review, Neural Networks, Proc. Acad. Sci., Cognitive Neurosciences*, and *European Journal of Psychology*).

The *Functional magnetic resonance imaging* component of this team is directed by Christophe Segeberarth and has extensive research experience in the field of functional magnetic resonance imaging (fMRI). Their research activities are centred on the development of non-invasive methods based mainly on magnetic resonance imaging (MRI) and spectroscopy (MRS) for the study of function and metabolism of the central nervous system (CNS). The research staff of this component includes physicists, biologists, and physicians, reflecting the highly interdisciplinary character of their research. The equipment in their laboratory currently includes three MR imagers for animal experiments (2.35 Tesla, 4.7 Tesla and 7 Tesla). Furthermore, the laboratory has access to a clinical imager (1.5 Tesla). Installation of a high field whole-body imager (3 Tesla) for the functional brain studies is scheduled for the end of the year 2000 and, crucially, would be made available for the research proposed in the present project.

Linkage to other teams

The functional magnetic resonance imaging (fMRI) unit has carried out a wide range of studies, has a longstanding history of highly interdisciplinary research, and is already actively involved in projects with the University of Liège and the Free University of Brussels. Recent studies carried out by this unit have included the perception of moving illusory contours, the involvement of the primary motor cortex during mental imagery of motor tasks, hemispheric specialisation during the processing of categorical and co-ordinate spatial relations. (Recent publications of this group have appeared in *Radiology, NMR Biomed., NeuroReport, J. Neuroimaging, Am. J. Neuroradiol.)*.

Key scientific staff

Dr. Bernard Ans, CNRS research scientist	15 %
Dr. Stéphane Rousset, Associate professor	15 %
Dr. Christophe Segeberarth, CNRS research scientist (neuroimaging)	15 %
Technician (different person depending on circumstances)	15 %

Recent significant publications

Baciu, M., Koenig, O., Vernier, M.P., Bedoin, N., Rubin, C. and Segebarth, C. Categorical and co-ordinate spatial relations: fMRI evidence for hemispheric specialisation. *NeuroReport 10*, 1-6 (1999).

Ans, B., Carbonnel, S., & Valdois, S. (1998). A connectionist multiple-trace memory model for polysyllabic word reading. *Psychological Review, 105*, 678-723.

<u>Free University of Brussels (Université Libre de Bruxelles)</u>

The main goal of the SRSC group at the Free University of Brussels is to contribute to our understanding of the role that conscious awareness plays in learning. To do so, the lab's projects involve empirical research with human subjects, computational modelling, and, more recently, neuro-imaging techniques. Members of the SRSC team are currently involved in about 10 different research projects, many of which are conducted in collaboration with colleagues around Europe. These different projects all aim to contribute to the development of a comprehensive theory of the role that conscious awareness plays in cognition and in learning, in particular. Their overall perspective on these issues is summarised in an important review article (Cleeremans, Destrebecqz, & Boyer, 1998). The SRSC's commitment to exploring the role of conscious awareness in cognition is further highlighted by the fact that they will act as local organiser for the fourth conference of the Association for the Scientific Study of Consciousness. This major international conference will take place in Brussels in June 2000.

Expertise

The SRSC's director, Dr. Axel Cleeremans, was trained in neural network modelling at Carnegie Mellon University (USA) where he collaborated with J.L. McClelland. He is a leading scientist in the domain of implicit learning and has also made significant contributions to our understanding of recurrent neural network models. Over the past few years, the SRSC has developed expertise in elaborating detailed neural network models of performance in various domains of cognition, and of designing and testing methods to explore the relationship between conscious and unconscious processing. More recently, the SRSC has also begun collaborating with the Neuropsychology Unit of the Université de Liège in order to buttress its empirical research with neuroimaging data. This combination of computational modelling, empirical research and neuroimaging studies is characteristic of the emerging field of computational cognitive neuroscience, and all of the SRSC lab members are involved to some degree in acquiring expertise in each of the relevant disciplines.

Linkage with other teams

Much of the SRSC's expertise and research interests are shared by other project members, particularly in the domain of computational modelling. *In terms of existing links*, R.M. French and Axel Cleeremans actively collaborate on a number of national research projects and editing projects. Further, members of four of the teams regularly contribute to the same conferences and workshops. *In terms of content*, learning, as a domain, is intimately related to cognitive development (D. Mareschal) in the sense that both involve long-term change to the processes and representations that subtend behaviour. Learning is likewise directly involved in categorisation tasks, albeit the links have seldom been explored directly. *In terms of methods*, the extensive expertise of the SRSC in using neural network modelling techniques to ground theory development is likewise shared by four of the teams. These existing collaborations, conceptual and methodological links mean that the teams will be able to share much of their separate expertise to address the central issues described in the project.

Key scientific staff

Dr. Axel Cleeremans, NFSR Research Associate, ULB Associate Professor	25%
Mr. Arnaud Destrebecqz, NFSR scientific collaborator	20%
Ms. Maud Boyer, ULB researcher	10%
Mr. Robert Reuter, ULB researcher	10%

Significant recent publications

Cleeremans, A., Destrebecqz, A., & Boyer, M. (1998). Implicit learning: News from the front. *Trends in Cognitive Sciences, 2*(10), 406-416.

Cleeremans, A. (1997). Principles for implicit learning. In D. C. Berry (Ed.), *How implicit is implicit learning?* (pp. 195-234). Oxford: Oxford University Press.

University of Warwick

The cognitive science research environment at the University of Warwick would provide a crucial and distinctive component to the training offered across the sites of this project. Warwick is one of the UK's major centres of cognitive science research, with about 10 faculty, many of them internationally known, and a large numbers of post-docs and PhD students working in this area. The director of the Warwick team is an internationally known figure in the cognitive sciences and has been awarded a number of major awards, including the British Psychology Society Cognitive Psychology Award (1995), the British Psychology Society Spearman Medal (1996) and the Experimental Psychology Society Prize (1997).

The project would be based in the Department of Psychology and the Institute for Applied Cognitive Science, which will set up within the next few months. The Institute will be a centre for cutting edge interdisciplinary research on cognition, across a range of disciplines at Warwick (e.g., Psychology, Mathematics, Computer Science, Warwick Business School, Education). It will be initially funded by a 950,000 pound grant for a state-of-the-art laboratory from the UK government Joint Infrastructure Fund, for which Nick Chater was the principal applicant, the only such grant to be awarded to a UK Psychology Department. This laboratory will house new ERP electrophysiological recording equipment to monitor on-line brain activity during cognitive tasks; eye-tracking equipment; equipment for monitoring perceptual-motor activity; and a Silicon graphics workstation for data intensive problems.

Expertise

The distinctive contribution of Warwick has two aspects. First, there is a strong emphasis on mathematical modelling, using information theory, Bayesian methods, and techniques from non-linear dynamics. This strong theoretical emphasis feeds into computational modelling and empirical testing. Second, is the strong emphasis on applications. The student and post-doc on the project would be directly exposed to existing collaborative work with the research divisions of Unilever and British Telecom, as well as research applying connectionist theories of learning to how children learn to read (funded by the Leverhulme Trust and Essex Local Education Authority), and a range of projects on cognition in the elderly. This research environment will encourage new scholars in cognitive science to consider how their research can have implications for the quality of life and for the competitiveness of European business.

A primary focus of the Warwick part of the project will be exploring a mathematical framework for the study of learning, based on a 'simplicity principle.' The central notion is that learning involves searching for patterns the data of past experience; and that the cognitive system prefers patterns to the extent that they provide concise ways of encoding that data. In this sense, the cognitive system is viewed as searching for 'simple' patterns. The mathematical work of this team would also bear on developing a better understanding of how pseudopattern information transfer works and why representational compression emerges in the dual-memory model as a result of this mechanism.

Linkage with other teams

These theoretical tools provide the basis for building models of human learning in specific, well-understood, domains, such as artificial grammar learning, an area where Chater has worked (e.g., Redington & Chater, 1996), and where there are strong links with Cleeremans' (ULB) internationally known research in this area. Previous work at Warwick has focussed on building computational models, based on standard statistical methods, with the goal of modelling human empirical data. In collaboration with Emmanuel Pothos (University of Wales at Bangor), preliminary work has already begun on building new formal and computational methods for both artificial grammar learning, as well as categorisation, based on a simplicity principle.

Key scientific staff

Professor Nick Chater	20%
Dr. Koen Lamberts, lecturer	5%
Professor Gordon Brown	5%

Significant recent publications

Chater, N. (1999). The search for simplicity: A fundamental cognitive principle? *Quarterly Journal of Experimental Psychology*, 52A, 273-302.

Chater, N. (1996). Reconciling simplicity and likelihood principles in perceptual organisation. *Psychological Review, 103,* 566-581.

Birkbeck College (University of London)

The principle role of the Birkbeck team is to establish the developmental relevance of the dual memory system. Exploring the developmental plausibility of the dual memory model sets constraints on its plausibility as a model of adult performance. Mareschal has training in both physics and experimental psychology. He has published numerous reports on studies that combine the use of connectionist modelling with behavioural studies involving infants and children (see Mareschal in press for a review). Johnson and Csibra both have a biological and psychological background and have a long-standing collaborative research programme developing HD-ERP methods for use with infants.

Expertise

The Birkbeck psychology department houses the newly formed Centre for Brain and Cognitive Development, funded by the Medical Research Council (UK). The Centre provides facilities for behavioural and HD-ERP testing of infants and adults. These include two 64-electrode and one 128-electrode HD-ERP Tucker Geodesic-net systems. The centre has 3 specially designed infant testing suites and a reception area There is a full-time receptionist who is also involved in actively recruiting new infant participants. Approximately 350 infants are tested per year. The Centre’s mission is to address fundamental questions in developmental cognitive neuroscience such as the nature of the interaction between genetic influence and environmental experience in normal and abnormal human development. It is headed by Professor Mark Johnson and currently involves 7 full-time senior researcher as well as a number of junior research staff and technicians. The Centre has collaborative links with research groups in France, Germany, Belgium, Canada, and the USA. These links are funded through grants from the EC Biomed IV, Human Frontiers, and British Council Science Programmes. Members of the centre have published in a broad range of developmental, neuroscience, and psychological journals (e. g., *Psychological Review, Journal of Experimental Child Psychology, Developmental Psychobiology, Science, International Journal of Psychophysiology*)

Linkage to other teams

Mareschal and French have published the results of previous collaborative research that explores the mechanistic basis of infant categorisation abilities. This work involved both connectionist modelling and behavioural studies with infants. It will form the basis of the further studies on infant categorisation. We anticipate close collaborations with the fMRI team in Grenoble in comparing imaging results of representation compression and information flow during the processing of category specific information. Equally, we anticipate working closely with the research group in Warwick in understanding how compression of information that occurs during the storing of exemplars in a dual memory system can lead to higher level, more global categorisations. The mathematical models will guide behavioural experiments exploring the level of categorisation in infants at different ages.

Key Scientific Staff

Dr Denis Mareschal	20%
Professor Mark Johnson	10%
Dr. Gregely Csibra	5%
Ms. Leslie Tucker	25%

Recent Significant Publications

Mareschal, D., Plunkett, K. & Harris, P. (1999). A computational and neuropsychological account of object-oriented behaviours in infancy. *Developmental Science, 2*, 306-317.

Csibra, G. Johnson, M. H., Tucker, L. (1997). Attention and occulomotor control: A high-density ERP study of the gap effect. *Neuropsychologia*, 35, 855-865.

6. Collaboration

This project has been structured so as to allow a maximum amount of collaboration and interaction among the five participating groups. These are intended to be meaningful working-level collaborations that go beyond the simple exchange of staff and information. From the table below, the extent of this collaboration and interaction can be seen. Since the central focus of the project is the use of connectionist models to explore the basic mechanisms of learning and forgetting, it is not surprising that the greatest area of overlap is in computer simulation.

UG = University of Grenoble, ULg = University of Liège, BC = Birkbeck College (Birkbeck College), UW = University of Warwick, ULB = University of Brussels

Research Theme

Methodology	Dual-network memory model	Infant development	Implicit/explicit learning	Optimisation/ compression/ simplicity principle
Theoretical	ULg, UG	ULg, BC	ULB, ULg, UW	UW, ULg, ULB
Experimental psychology	ULg, BC, UG	BC	ULB, BC	ULB, BC, UW
Neuro-imaging (fMRI / ERP)	ULg, UG, BC	BC	ULB, UG	--
Computer simulation	ULg, BC, UG	ULg, BC, UW	ULB, ULg, UW	ULg, UW, ULB

Work on the dual-network memory model involves the highest degree of collaboration of all of the work on basic learning and forgetting mechanisms described in this project. Three of the universities in all three of the participating countries have been involved in work related to this subject in the past. The main work will involve a tight collaboration between the University of Liège, Birkbeck College, and the University of Grenoble.

The work on the mechanisms of implicit learning has been the subject of collaboration between the University of Liège and the University of Brussels in the past (e.g., ULg and ULB jointly organised an international workshop at the University of entitled, “The role of implicit learning and implicit memory in representing the world”). Further, the sequential learning tasks developed at ULB and used in experimental tests of implicit learning will be modified and used with subjects under fMRI observation in order to detect which regions of the brain are active. The University of Warwick has also been very active in this area. Their contribution to this work will be mathematical and computational

A fundamental aspect of this proposal to understand the early development of the basic mechanisms of learning and forgetting. The developmental work will be carried out on infants at the Centre for Brain and Cognitive Development (BC). The Centre provides specially designed suites for testing infants. It also has well established facilities and trained staff for carrying out ERP studies with infants. All developmental work will be carried out at BC. The investigations into the mechanism of learning and forgetting category specific knowledge will be carried out in collaboration with French (ULg). The ERP studies will be carry out and interpreted in conjunction with the fMRI studies (UG). Understanding the developmental processes involved in category formation through compression will be carried out in collaboration with Chater (UW).

Finally, even those teams that are not collaborating directly on a specific dimension of the project can benefit from the intellectual climate of 5 partner institutions working around a common theme.

7. Organisation and Management

Good communication/monitoring progress

To ensure the best possible communication between the various teams and to ensure that all teams are aware of the work in progress of the other teams, we propose:

- *Annual workshops*: At the annual workshops (see section 10), we will also have an organisational meeting where the heads of participating institutions will assess the overall progress of the project, identify possible problems and devise strategies for dealing with them, and review goals for the upcoming year.
- *Technical reports*: All junior researchers (doctoral students and postdoctoral researchers) will be required to produce a technical report describing the progress made on their component of the project. These reports will be circulated to all other participating institutions.
- *Project-related Web page*: A Web page devoted to the project will be maintained by ULB. The Web page will contain up-to-date information concerning the status of the project and will pay particular attention to the target objectives. It will include copies of all technical reports, conference abstracts and papers, and journal publications based on the research carried out in the project.

Practical steps taken for effective dissemination of results

We will present the results of our work at international conferences, in particular: Cognitive Science Society Conference, Psychonomics, European Society for Cognitive Psychology, European Society for the Study of Child Development. In addition, papers from work done in this project will be published in peer-reviewed journals. *One of the major areas of emphasis for doctoral students and post-doctoral researchers will be the publication of their results in international journals.* Considerable emphasis will be placed on this aspect of the project. The ability to publish in English in major international journals goes beyond simply having good results. Precise skills must be mastered in order to communicate results in journals. These skills will be explicitly taught to the researchers trained in this project.

Network Management Structures

The University of Liege will form the hub of a wheel of communication with all of the other teams. It will be responsible for overseeing the collective progress of the network and for disseminating information to all members of the networks (primary axes of communications). Partners will communicate directly with each other while working on collaborative projects (secondary axes of communication. (see Chart on the following page)

Progress of the doctoral students and postdoctoral researchers

Progress of doctoral and postdoctoral researchers will be managed and monitored from within each institution. Every 6 months, the senior scientist at each participating university will submit a brief progress report to the project co-ordinator at Liege. The co-ordinator will compile the reports and redistribute them to all the project members. Areas of concern will be flagged if necessary. The progress reports will be consolidated at the annual workshops.

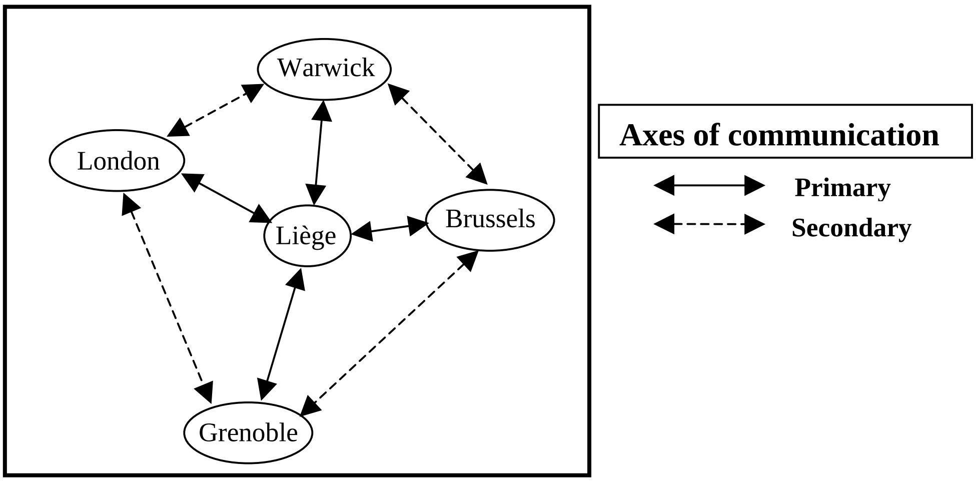
Language

All of the participating senior members are fluent in both French and English. This will enhance the transfer of knowledge between the participating institutions. This is of crucial importance in this type of research training project because it will facilitate the exchange of pre- and postdoctoral researchers among the institutions.

Experience of the network co-ordinator

The network co-ordinator has an extensive career in academia which has included organising international conferences, setting up a cognitive science program at the university where he taught in the United States. He was recently selected to serve as a senior co-ordinating editor for the Macmillan Encyclopaedia of Cognitive Science (this involves co-ordinating the contributions of over one hundred academics across the world), and runs his own research unit at the University of Liège. The co-ordinator was the main motor in putting together this proposal.

Chart for “Organisation and Management”



Axes of communication defining the organisational structure of the project.

8. Training need

All of the groups participating in this grant are committed to the development of the interdisciplinary field of cognitive science in Europe and to the training of European cognitive scientists. Cognitive Science is the interdisciplinary study of intelligent and adaptive behaviour. It builds on findings in psychology, philosophy, mathematical modelling, neurosciences, and computer science. It has direct applications to artificial intelligence, information technology, educational methodology, and the understanding of reasoning and problem solving.

Research in cognitive science, especially in those areas centred on neural network research, has seen explosive growth in the United States over the last decade, an explicit acknowledgement of the value of an interdisciplinary approach to studying cognition. The European Union significantly trails the United States in this field. Based on membership figures of the Cognitive Science Society, there are *5.4 times as many active researchers in cognitive science in the US as there are in the EU.* Further, when adjustments are made for population differences, we see that there are *2.5 times as many technical publications in cognitive science coming from the United States compared to the EU.* The following graphs clearly show these disparities between the EU members countries and the United States.

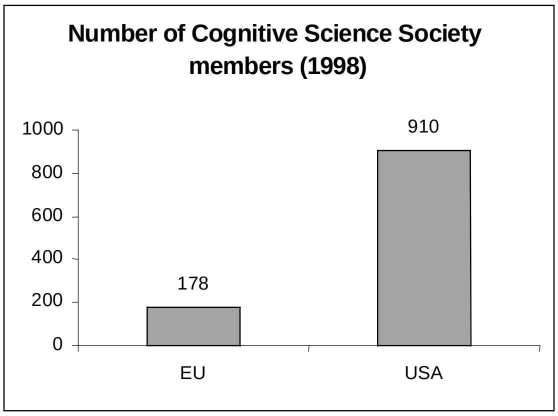


Figure 1. Disparity between cognitive science research in the E.U. compared to the U.S.A. based on the number of active members in the Cognitive Science Society.

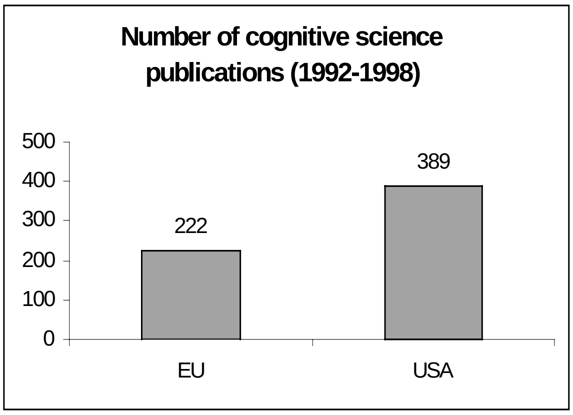


Figure 2. Disparity in the number of cognitive science publications between EU countries and the United States (1992-1998). Note that the population of the USA is approximately 30% less than that of the EU, while the number of US publications is 75% greater than EU publications.

In addition, recent advances in non-intrusive neuro-imaging techniques, Functional Magnetic Resonance Imaging (fMRI) and Evoked Response Potential (ERP), have led to substantial breakthroughs in the understanding of the link between brain and cognition. This area continues to be one of the most promising tool for understanding intelligent behaviour. Training young researchers in these techniques, especially in neuro-imaging and connectionist networks, will ensure that Europe will remain at the cutting edge of world developments in the cognitive sciences.

The training in this network will provide interdisciplinary expertise in computational and experimental techniques, language skills (by virtue of working with members of the network from other nations), experience working in the research cultures of other European nations, and an opportunity to establish transnational contacts for future pan-European collaborative research projects.

Enhanced possibilities for future employment

The interdisciplinary nature of the training provided by this network will ensure a far greater ability to find employment upon completion of their PhD or post-doctoral research. The students involved in this project acquire skills in computer modelling, in practical experimentation and data analysis, and will have participated in the use of state-of-the-art neuro-imaging equipment. Their demonstrated mastery of this range of difficult skills, acquired in international research laboratories, will make them highly competitive in the job market both within as well as outside of academia, and will greatly increase their mobility within the European Union..

9. Justification of the Appointment of Young Researchers.

University of Liège: The ULg team is requesting funding for one 4-year doctoral student and one 1-year post-doctoral researcher. One 4-year doctoral student: The student selected for this position would have a strong background in both experimental psychology and computing. This student would be expected to develop both connectionist computer simulations and psychophysical experiments. The simulations would involve extensions of work done by Mareschal and French on infant category acquisition and category-specific deficits. The psychological experiments would involve interference with category development after interruption of REM sleep that would test the consolidation hypotheses of the dual-memory model. The student will also spend part of his/her time at both Birkbeck and Grenoble to learn techniques of infant experimentation (Birkbeck) and gain hands-on experience with fMRI technology (Grenoble). One 1-year post-doctoral researcher: This position will be offered to an experienced neural network modeller. The goal would be to render the dual-memory system as neurally realistic as possible, for example, replacing standard sum-and-squash computing units with more realistic neurone-like units. In addition, he/she would be responsible for exploring new mechanisms of pseudo-pattern generation and information transfer between the two memory areas of the model.

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University of Grenoble: The Grenoble team is requesting a four-year position for a graduate student and a two-year position for a post-doctoral researcher. One 4-year doctoral student: This person would be involved in the on-going work of neural network simulation of retrograde amnesia, as well as in clinical and behavioural investigations using functional Magnetic Resonance Imaging (fMRI). His or her PhD work would, therefore, clearly benefit from the expertise of the Grenoble team and of the other European teams involved in this project. One 2-year post-doctoral researcher: This person would be involved with the neuro-imaging facility. As previously mentioned, a high-field whole-body imager (3 Tesla) will be installed in Grenoble in the upcoming year. While high-field whole-body imagers are ultimately capable of providing higher sensitivity than clinical imagers performing at 1.5-2 Tesla, considerable effort will be needed to optimise the performance of the 3-telsa instrument. The Grenoble group will be responsible for this and, consequently, would like to invite a post-doctoral physicist for a period of two years. This physicist would have to have a strong background in the field of MR acquisition methods, preferably on systems similar to the one to be installed in Grenoble. In return, this post-doctoral researcher would acquire expertise in functional MRI, of MR acquisition, of data processing and in the connectionist modelling techniques used in this project.

Free University of Brussels (ULB): The ULB team is requesting funding for a 4-year doctoral student and a one-year post-doctoral researcher. ULB’s part of the project involves: (1) Empirical research targeted at developing sophisticated behavioural methods to assess the relative contribution of implicit and explicit influences on sequence learning, (2) the adaptation of such methods for use in the context of neuroimaging studies, and (3) the development of a detailed computational model of performance in sequence learning tasks, in particular with respect to the time course of processing. One 4-year doctoral student: Because the first two components are closely related and require specific training in cognitive psychology and in neuroimaging techniques, they would be undertaken by a doctoral student.. This graduate student's main responsibility would be to conduct empirical research in Brussels and to actively collaborate to the development of corresponding neuroimaging studies in Grenoble. One 1-year post-doctoral researcher: The third component of the project requires considerable expertise in computational modelling, programming, and formal methods, as well as extensive experience with several empirical literatures dedicated to choice reaction time, memory and learning. It is suggested that a post-doctoral research assistant with a strong background in computational modelling and cognitive science would best fulfil this position's requirements. This person's main responsibility would be to undertake the development of a computational model relevant to the issues addressed in components 1 and 2.

Birkbeck College: The Birkbeck team requests one full-time postdoctoral research assistant for 2 years, and 1 full-time doctoral student for 3 years (the time required to complete a PhD at Birkbeck). The research carried out at Birkbeck will involve a combination of behavioural and Evoked

Response Potential (ERP) studies as well as connectionist modelling. One 2-year post-doctoral researcher: A post-doctoral is required to carry out the core of the work because of the complexity of the computational modelling and the subtlety of interpreting ERP data. We expect to recruit a post-doc with prior experience of ERP work with adults. The post-doc would benefit by learning: (1) ERP methods appropriate for testing infants, and (b) connectionist modelling methods. The post-doc would be appointed during years 1 and 2 of the project. One 3-year doctoral student: Doctoral students require more training and only become effective independent researchers towards the middle of their appointment. We would appoint the doctoral student in years 2, 3, and 4 of the project. In year 2, the student would focus predominantly on behavioural studies of infants and would also work as an assistant to the post-doc, testing behavioural predictions of the model and ERP results. This first year of their degree would constitute an apprenticeship year in which the student learnt the basis of ERP methodology. In years 3 and 4, the student would be expected to undertake independent work involving a combination of ERP and behavioural studies. By the end of their degree, the student will have acquire (1) skill in testing infant behaviours, and (2) an ability to use ERP methods with infants.

University of Warwick

The part of the project at the University of Warwick requires an 18 month post-doctoral position, and a 4 year doctoral student. One 18-month post-doctoral position: This position would be filled by a candidate with a strong formal background, from cognitive science, mathematics, statistics, computer science or related disciplines, who would be able to apply advanced mathematical methods, especially those from Kolmogorov complexity theory, information theory and Bayesian statistics, to cognitive processes involved in learning and memory. The candidate would build on the existing corpus of work using these methods by Nick Chater, with whom a close working collaboration would be expected. The position would also involve developing computer software to implement these ideas in specific cognitive models. This position would provide a crucial training resource, particularly as the combination of formal skills, and detailed knowledge of experimental and applied aspects of cognitive science is presently relatively rare in Europe. One 4-year doctoral student: This position would focus on experimental and applied aspects of this theoretical work, although in the later part of the project, the student would be expected to be able to contribute directly at a theoretical level. The training requirements for such work are considerable, involving a mixture of experimental, statistical, and formal skills, as well as a rich general understanding of cognitive science. Thus a 4 year doctoral studentship is requested, rather than the normal 3 year term in the UK. The student would be expected to attend a large range of graduate courses, particularly in the first year of study, both in the Department of Psychology, and the Departments of Mathematics and Computer Science. The strong focus of the Warwick Psychology Department on Cognitive Science, and the large number of current post-docs and post-graduates would provide a rich training environment.

Recruitment of doctoral students and post-doctoral researchers

The international reputation of the researcher teams in this project should mean that recruiting people for the proposed positions will not pose a problem. In order to ensure quality recruitment of candidates, we will post announcements of these positions in widely-read electronic newsgroups and mailing lists devoted to the themes of this project (e.g., the “connectionists” mailing list, the “machine learning” list, etc.) In addition, we will specifically target universities, such as Edinburgh, Sussex, Lyons, etc., that have undergraduate programs in cognitive science research groups in Europe. If necessary, we will place announcements in relevant cognitive science and cognitive neuroscience journals. Finally, given the fact that women are currently under-represented in cognitive science, a particular effort will be made to attract qualified women for these positions. Because of the added cost of living in London, the standard London weighting is added to the salaries of staff appointed at Birkbeck to attract to highly qualified candidates.

Young researchers to be financed by the contract				
Participant	Young pre-doctoral researchers to be financed by the contract (person-months) (a)	Young post-doctoral researchers to be financed by the contract (person-months) (b)	Total (a + b) (c)	Scientific specialities in which training will be provided (d)
1. ULG	48	12	60	M-13, S-04
2. Grenoble	48	24	72	M-13, L-18
3. ULB	48	12	60	M-13, S-04
4. Birkbeck	36	24	60	M-13, S-04, L-18
5. Warwick	48	18	66	M-13, M-06
Totals	228	90	318	

Specifically, M-13 is meant to indicate computation modelling, in particular, connectionist modelling; S-04 indicates traditional psychophysical experimentation; L-18 indicates the neuro-imaging (fMRI) techniques used at the University of Grenoble; and M-06 is mathematical modelling, complexity theory, etc. See justification by individual partners for further breakdown of numbers.

10. Training Programme

Because of the interdisciplinary nature of Cognitive science, the network will endeavour to provide training in multiple techniques. Although the student will be registered at one institution, they will be encouraged to complete at least one 12 months period a partner institution in another country as part of a training programme that guarantees meaningful work-level collaborations.

Provisions for ensuring quality training

(1) Doctoral students will be integrated within existing graduate training programmes. They will be provided with methodology and statistics training on a par with other PhD students registered at the Host University.

(2) Both postdoctoral and pre-doctoral students will be integrated within an existing research laboratory. The laboratories provide a nurturing environment for discussion and intellectual development. Students will receive technical training specific in accordance with the speciality skills of their host institution. Students will also be required to attend regular lab meetings and seminar series.

(3) A mentor system will ensure the early identification of possible difficulties. Besides regular meetings with their supervisors, PhD students will be paired with a postdoctoral student working in a related field. The mentor system gives students an opportunity to turn to someone other than their supervisor for advice.

(4) Students and post-doctoral researchers will be required to draft annual progress reports to be published as internal technical reports. These will be circulated to other laboratories in the network to ensure that all members are aware of developments in different aspects of the project

(5) Students will be given annual feedback about the progress and quality of their research from their supervisors. Target aims and objectives for the coming year will be established at the beginning of every year.

(6) Where necessary, pre-doctoral students will be encouraged to attend intensive “language for academic use” courses on offer at the host universities

(7) Four Annual workshops will be organised.

These workshops will serve a dual purpose. Pre- and postdoctoral student will be required to present the results of their research during the past year. These presentations will provide a means of monitoring the progress of individual students as well as the progress of the project as a while. They will also provide students with experience at presenting scientific research and help develop their communication skills. *Communicating* scientific research is too often neglected in doctoral programs. Doing research is one thing, knowing how to communicate the results appropriately is another. The ability to communicate effectively is of the utmost importance for ensuring the future employment of these junior researchers.

In addition, each workshop will be accompanied by a half-day tutorial introducing methodological issues in: Neuro-imaging techniques, implicit learning, testing infant memory, and connectionist modelling This will ensure that all junior researchers are exposed to all the techniques employed in the collaborative project. These tutorials will be complemented with sessions on how write scientific papers for publication in international journals, on the techniques of oral presentations at international conferences and on poster presentation. The students will be required to prepare oral presentations at these workshops. In addition, information on European sources of research funding, how to select appropriate sources of funding, and how to write grant proposals, will be distributed. Together these sessions will guarantee are in the best possible position to enter the job market upon completion of their training. It is expected that these workshops will be hosted in Liege, London, and Grenoble. All partners have a successful prior record of training doctoral students.

11. Multidisciplinarity in the training programme

Mutlidisciplinarity is the essence of cognitive science. A key purpose of this proposal is to train people who are equally skilled in a number of cognitive science sub-disciplines.

Doctoral students and postdoctoral fellows will be exchanged between labs with complimentary specialities. Familiarity with connectionist modelling is shared by all institution and will constitute the common language by which inter-institutional research will be motivated. Aside from the computational modelling expertise shared by all of the partner institutions, the specialities of each institution are: experimental and ERP infancy research (Birkbeck), implicit learning (ULB), mathematical modelling and theory building (Warwick), neuroimaging (Grenoble), and interference phenomena in memory (ULg).

To maximise the training potential of this interdisciplinary network, doctoral students in this project will be expected to spend 12 months in at least one, preferably two, different laboratories outside their host institution. This will guarantee a multinational distribution of students and an accumulation of diverse skills that should, in the future, enable students to embark successfully in Cognitive Science research throughout Europe.

12. Connections with industry

While the project as a whole has no formal connections with industry, connectionist neural network research is being actively applied in many areas of engineering and computer science (e.g., image and voice recognition, market analysis, medical diagnosis, satellite guidance). Because the young researchers participating in this project will become particularly well qualified in connectionist network technology, this will give them a significant advantage in any subsequent industrial job requiring knowledge of connectionist networks. In addition, one of the teams, the University of Warwick, collaborates actively with the research divisions of Unilever and British Telecom, and applies connectionist theories of learning to how children learn to read (funded by the Leverhulme Trust and Essex Local Education Authority), and a range of projects on cognition in the elderly

13. Financial information

The figures in the table below are in accordance with the financial guidelines set out in Chapter 4 of this Guide for Proposers. In particular,

- in all cases, the amount of funding to be used to pay for the salaries of young researchers exceeds 60% of the total amount (the values range from 60% to 78%);
- the average funding request per participating team does not exceed 200,000 euros;
- the total amount does not exceed 1,000,000 euros for the five participants;
- no funds will be used to procure durable equipment;
- the university overheads are specifically indicated.

Financial information on the network project				
Participant	Personnel and mobility costs related to the appointment of young researchers (euro) (A)	Costs linked to networking (euro) (B)	Overheads (euro) (C)	Totals (euro)
1.Liège (ULg)	131,382	42,000	41,618	215,000
2. Grenoble	141,391	28,609	30,000	200,000
3. Brussels (ULB)	131,382	30,000	12,147	173,529
4. Birkbeck	162,963	10,350	34,622	207,935
5. Warwick	113,316	44,067	31,477	188,860
Totals	680,434	155,026	149,864	985,324

Salaray costs correspond to the staffing distribution described in section 10. Salary costs are higher in London because a standard London weighting factor has been added due to the added cost of living in London.