A model of emotional influence on memory processing

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Abstract

To survive in a complex environment, agents must be able to encode information about the utility value of the objects they meet. We propose a neuroscience-based model aiming to explain how a new memory is associated to an emotional response. The same theoretical framework also explains the effects of emotion on memory recall. The originality of our approach is to postulate the presence of two central processing units (CPUs): one computing only emotional information, and the other mainly concerned with cognitive processing. The emotional CPU, which is phylogenetically older, is assumed to modulate the cognitive CPU, which is more recent. The article first deals with the cognitive part of the model by highlighting the set of processes underlying memory recognition and storage. Then, building on this theoretical background, the emotional part highlights how the emotional response is computed and stored. The last section describes the interplay between the cognitive and emotional systems.

1 Introduction

Intensive research in neuroscience has established a close link between emotion, cognition, and action. In recent years, researchers in artificial intelligence and robotics have attempted to build artificial systems where emotional and motivational mechanisms modulate cognitive mechanisms (e.g., Pfeifer & Scheier, 1999). However, these attempts have so far been directed at modelling animal behaviour and/or relatively simple tasks, and did not use current knowledge of the human brain. We suggest that, in order to understand how emotion, motivation, cognition and action interact in complex systems it is necessary to use the information provided by current research in neuroscience.

The aim of this paper is to propose a model linking emotion and cognition that is based on recent developments in neuroscience. In particular, we want to identify the learning and memory mechanisms that enable memories to be influenced by emotions. We also discuss how the proposed mechanisms relate to chunking, a mechanism that has been shown to be central to cognition from simple animals to human experts. While we do not present a computer or robotic implementation of these mechanisms, we believe that they will be of interest to researchers building such implementations and others attending this symposium. In particular, we hope that the ideas presented in this theoretical paper will entice colleagues to build computer or robotic systems that will allow testing them empirically.

The first section presents a model of memory processing. The model describes the mechanisms behind object recognition and storage, and spells out the role of the cognitive central processing unit (CPU). In the second section, we present a model of emotional processing. The objective is to show how an affect is generated from recognised objects and to make clear the relation between the retrieval of stored information and that of emotional response. In this section, we also introduce the concept of an emotional CPU, which computes the emotional response. Finally, we present an integrative model that consists of the two previous components. Thus, a direct link is made between memory storage and emotional processing. The interaction between the two CPUs is crucial, as it is the means by which the emotional responses are actually influencing cognitive processing.

2 The cognitive system

2.1 Bottom-up processing

The recognition of an object is done when a particular configuration of neurons coding for the object and its properties is activated. Such distributed neural networks, which activate a small number of modules concerned with different types of information (spatial, auditory, etc…), are known as *cell assemblies* (Sakurai, 1999).

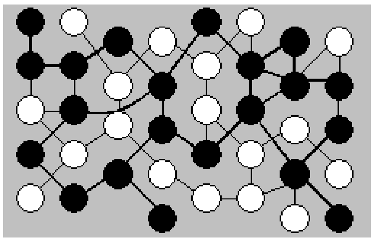

Figure 1. A cell assembly (CA). Cells possibly located in distinct parts of the brain are activated jointly.

A cell assembly is distributed in distinct brain areas. The cells forming a cell assembly are closely interconnected (bold links in the Figure 1): the activation of a neuron belonging to the assembly is likely to activate the other neurons of the assembly. This propagation law makes the CA act as a unit: when a subpart of the CA is activated (e.g., the property of an object is recognised), the spreading activation is very likely to activate all the CA, so that the object is recognised even if some of the information is missing (e.g., when an object is partially hidden).

As soon as an object is recognised, the neural coordinates serve as a pointer for *short-term memory (STM)* storage. It is likely that top-down inhibitory control processes are carried out at this stage, specifying whether or not the recognised object is of interest and should accordingly be stored in STM.

2.2 The functions of the cognitive CPU

When a CA is activated (i.e., an object is recognised), a pointer that codes for this CA is stored in STM. As each recognised object activates a CA, the role of the cognitive CPU is to compute an overall representation of the external milieu by connecting the active CAs. This computation is likely to have two main consequences:

(i) To activate new pathways *between* the cell assemblies.
(ii) To modify the dynamics *within* each cell assembly. The spreading activation of any cell assembly is now an input for all others.

The result of this computation is the emergence of a new *dynamic neural network* (DNN) that represents the external milieu. The DNN is maintained active by CPU processing. Unlike CAs, the DNN needs an active control to remain active.

2.3 Consolidation: Long-term memory

The question now arises as to how the DNN may be encoded more permanently. In line with this theoretical framework, *long-term memory (LTM)* storage refers to the processes that change the neural network activity computed by the cognitive CPU into one consolidated memory trace. Neuroscience is bringing converging evidence supporting the view that the medial temporal lobe mediates information storage in the sensory cortices by generating structural changes via mechanisms like long-term potentiation (Kandel, Schwartz, & Jessell, 2000). We suggest that, following the computation of a new DNN (see previous section), the CPU supervises its consolidation into durable memory traces. Such consolidation is done through the synthesis of new synapses consolidating the new connections (Kandel et al., 2000). As a result of the consolidation of memory traces, a new durable CA emerges, and thus a new object can be recognised. We note that the new CA encompasses the previous CAs coding for the individual objects. This process of building new patterns by accretion of previous ones is known as chunking (Gobet et al., 2001).

Chronologically, the chain of reactions leading to the emergence of a new CA is initiated by bottom-up processing which generates the recognition of objects. As soon as recognition is done, the CPU computes a dynamical network that represents the situation in STM. Thanks to the consolidation process, the dynamical network evolves into a structural network. This leads to the emergence of a new cell assembly that could be activated by discrimination of entrant stimuli.

So far, we have presented a theoretical framework for memory recognition and storage. The key component is the cognitive CPU, the function of which is twofold: first, to compute the representation of the external milieu based on the recognised objects and, second, to consolidate the new computed representation in memory. In the next section, we turn our attention to emotional processing.

3 The emotional system

3.1 The functions of emotions

The information processed by the cognitive system, although useful for survival, lacks any utility value. However, a living system needs to know the utility of the objects in the environment in relation to a given task. Emotions, which play this role, have been defined by Rolls (2003) as "*states elicited by rewards and punishers*" (p. 552). A reward is what a living system is ready to work for, and a punisher is what it tries to avoid. Emotions are thus goal-directed, and values depend on the goal (the motivator). For example, when one is cooking, the goal is to prepare good food (motivator). Each element taking part in the action of cooking has its own utility (emotional value: reward or punisher). In general, emotions structure the environment by tagging objects with an emotional value relative to a goal (the motivator). The emotional physiological response consists in preparing the body for action (Frijda, 1993). What remains to be spelled out is how the emotional system tags information from the environment, and how this influences high-level cognitive processes.

3.2 Emotional processing

A key issue in emotion research is how a neutral stimulus comes to generate emotional responses with experience. A good example from this field of research is LeDoux's (2002) model of fear conditioning, which links emotion and cognition in the simplest way: a stimulus, previously neutral to the animal, is paired to an emotional response. This model of fear learning illustrates that emotional responses are stored, and that they can be linked to stored objects. As soon as the object is recognised, the emotional response is retrieved. Fear is an unlearned punisher, thus likely to be genetically coded (Rolls, 2003). But some emotions are experience-dependent and thus ontologically built. Therefore, we need to provide an explanation of how new emotions are computed from previous emotional responses. This necessary flexibility suggests the existence of a system regulating emotional responses.

A living system has thus to be able to process emotions that do not induce automatic responses. In addition, different objects are likely to induce different emotions, giving rise to internal conflicts. To deal with these issues, we propose a model where three steps of information processing are postulated. In the first step, any recognised object in a scene activates its associated emotional response. In the second step, the emotional CPU computes an overall emotional response in the same way as the cognitive CPU computes an overall representation. That is, the emotional responses are physiological levels that encode objects utility values; in order to integrate the emotional responses, the CPU sums the utilities of all objects. In the third and final step, the computed emotion is felt by the individual as related to the representation of the external milieu.

This model, which spells out how recognised objects can retrieve different emotions, explains how the living system generates new emotions based on the emotional responses of the recognised objects. But the living system also needs a way to combine the overall emotional response with the representation computed by the cognitive CPU. This issue is addressed in the next section.

4 Cognition and emotion

4.1 Empirical evidence on the influence of emotion

There is substantial empirical evidence supporting a close relationship between the cognitive and emotional systems, and two examples will suffice here. Erk et al. (2003) demonstrated that non-emotional objects are better encoded in memory when they have been associated to a strong enough emotional clue. That is, the emotional context modulates the encoding of memories with no prior emotional value. Kilpatrick and Cahill (2003) showed emotionally loaded film clips to their participants, and, using neuroimaging techniques, showed that the amygdala, a brain structure related to emotional processing, influences the hippocampus, a brain structure related to memory consolidation.

4.2 Emotion and memory storage and retrieval

The emotional and cognitive processes are both parallel and serial (see Figure 2).

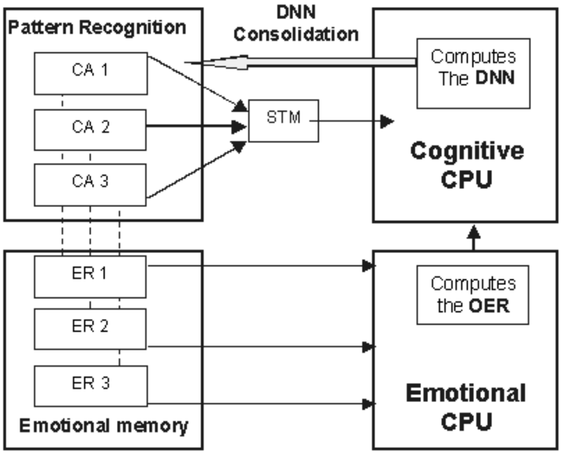

Figure 2. The information flow: a summary

In order to clarify them we divide the chain of actions in two steps. The first step is the computation of both the representation of the external milieu by the cognitive CPU, and the computation of the emotional response by the emotional CPU. The second step, explains how the two CPUs cooperate in order to link and consolidate the dynamic neural network

representing the external milieu to the computed emotional response.
Figure 2 also describes the two processes that are running in parallel: one cognitive, the other emotional. The cognitive process was explained in the first section of the paper. The emotional process is divided in two steps. Firstly, each active CA induces the retrieval of its associated *emotional response (ER1, ER2, ER3*). Secondly, the emotional CPU computes an *overall emotional response (OER)* by combining the retrieved emotional responses. The OER is the emotional utility value of the representation coded by the DNN. The OER is at the origin of the emotional influence of memory as it modulates the speed of the DNN consolidation: The more intense the OER, the more facilitated the consolidation of the DNN will be. In addition to this, the cognitive CPU consolidates the link between the DNN and the EOR. As a result of this process, the DNN is associated to the computed emotional response.

In summary, by means of the consolidation process, the cognitive CPU has created a new representation and has linked it to a new emotional response. When the representation is activated again in the future, the corresponding emotional response is retrieved.

5 Conclusions

The model provides an explanation of how recognised objects generate a representation of the external milieu and how this representation is turned into a structural feature of the system. In doing so, we put forward a biologically valid explanation for the influential concept of chunking (Gobet et al., 2001). The model also explains how emotional information is linked to objects stored in memory. Tagging allows the system to retrieve the value of an object upon its recognition. The computations that follow ensure the necessary flexibility of high-level cognition. Both for memory and cognition, we have postulated that a CPU played a key role in controlling how cell assemblies are combined together so that they can be recognised as a unit in the future.

Testing this theory will require a combination of empirical and theoretical research. That is, it will be necessary to develop computer programs or autonomous robots whose parameters will be set by both biological and psychological data. Then, experiments should be run to test whether agents would perform better in complex and dynamic environments with the presence of the emotional mechanisms described in this paper. If supported empirically, our theory would provide a powerful conceptual framework for computer science and robotics, as it would offer an explanation of how emotions help humans to structure their perceptual space.

There is no doubt that understanding—and, in a computational model or robot, controlling—the dynamics of cell assembly raises serious theoretical and practical problems. But then, the implicit message of this paper is perhaps that complex processing is necessary when emotions enter the scene and, in corollary, that there are limits in what simple autonomous agents can do without emotions modulating the way they perceive and process information.

References

Erk, S., Kiefer, M., Grothe, J., Wunderlich, A.P., Spitzer, M., & Walter, H. (2003). Emotional context modulates subsequent memory effect. *NeuroImage, 18*, 439-447.

Frijda, N. (1993). Moods, Emotions Episodes, and Emotions. In H. Lewis. & J.H. Hairland (Eds). *Handbook of Emotions.* New York: Guilford press.

Gobet, F., Lane, P.C.R., Croker, S., Cheng, P.C.H., Jones, G., Oliver, I., & Pine, J.M. (2001). Chunking mechanisms in human learning. *Trends in Cognitive Sciences, 5*, 236-243.

Kandel, E.R., Schwartz, J.H., & Jessell, T.M. (2000). *Principles of neural science*. New-York: McGraw Hill.

Kilpatrick, L., & Cahill, L. (2003). Amygdala modulation of parahippocampal and frontal regions during emotionally influenced memory storage. *NeuroImage, 20*, 2091-2099.

LeDoux, J. (2002). *Neurobiologie de la personnalité.* Paris: Odile Jacob.

Pfeifer, R., & Scheier, C. (1999). *Understanding intelligence*. Cambridge: MIT Press.

Rolls, E.T. (2003). Vision, emotion and memory: From neurophysiology to computation. *International Congress Series, 1250*, 547-573.

Sakurai, Y. (1999). How do cell assemblies encode information in the brain? *Neuroscience and Biobehavioral Reviews, 23*, 785-796.