Artificial Neural Emotions and Emotional Memory

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Abstract
Artificial feelings and emotions are beginning to play an increasingly important role as mechanisms for facilitating learning in intelligent systems. Here we present an architectural framework for artificial neural emotions through the use of an emotional memory system, based on Dr. Peter Levine’s Autonomic Nervous System States. Tying the notions of Human Autonomic Nervous System States to an artificial Spatio-Temporal memory system, facilitated through the use of an Artificial Cognitive Neural Framework provides the foundation for a system of basic artificial emotions for a Genetic, Neural Processing Environment capable of emotional learning and processing.

We believe this has the potential to revolutionize neural processing environments by allowing emotional memories and emotional learning to facilitate coalitions and cooperation between artificial neural intelligent software agents. We believe shared emotional states between intelligent software agents will more easily allow information sharing between agents, providing the constructs for “Cognitive Economy” in intelligent systems.

Introduction
For the last several years, research has continued and early development has been undertaken into a hybrid, fuzzy-neural processing system with genetic learning algorithms to provide a modular artificial neural architecture (Crowder, 2001_02). This architecture is based on a mixture of neural structures that add flexibility and diversity to the overall system capabilities. In order to provide an artificially intelligent processing environment that is continually adaptable, we believe the system must possess the notion of artificial emotions that allow the processing environment to “react” in real-time as the systems outside environment changes and evolves.

The purpose of this paper is to describe an Artificial Cognitive Neural Framework (ACNF) (Crowder, 2001_03) which allows for “conscious” software agents that carry “emotional memories,” based on Dr. Levines Autonomic Nervous System States (Levine, 1997). These conscious software agents are autonomous agents that sense the environment and act on it, based on a combination of information memories (explicit spatio-temporal memories), emotional memories (implicit inference memories), and outside stimulus from the environment. We will describe the constructs for basic emotions and short & long-term memories (Crowder, 2002_02). The long-term memories (three dimensional spatio-temporal memories) provide identification, recognition, and categorization functions as well as identification of basic feelings (Nervous System States). The short-term memories (non-recurrent associative memories) provide preconscious buffers as a workspace for internal activities (Eichenbaum, 1002). A transient episodic memory provides a content-addressable associative memory with a moderately fast decay rate (Crowder, 1999_01).

Artificial Cognitive Neural Framework (ACNF)
In the ACNF, first the unconscious artificial neural perceptrons, each working toward a common goal, form a coalition. These coalitions will vie for access to the problem to be solved (Crowder, 1999_03). The resources available to these coalitions depend on their combined nervous system state, which provides information on the criticality of their problem to be resolved. This nervous system state is defined by the Autonomic Nervous System States chart (Levine, 1997).

Based on this nervous system state, information are broadcast to all unconscious processes in order to recruit other artificial neural perceptrons that can contribute to the coalition’s goals (Crowder, 2001_1). The coalitions that understand the broadcast can then take action on the problem. What follows is a description of the overall ACNF architecture in the context of artificial neural emotions and artificial nervous system states.
ACNF Architecture

Figure 1 illustrates a high-level view of the ACNF. This is similar to an AI Blackboard system, except that it is greatly extended to allow for system-wide action selection. The three main subsystems within the architecture are the Mediator, the Memory System, and the Cognitive System. The Mediator gathers information and facilitates communication between agents. The Mediator takes information from perceptrons and from coalitions of perceptrons and updates the short-term, long-term and episodic memories. The information available in memory (what the system has learned) is continually broadcast to the conscious perceptrons that form the cognitive center of the system (i.e., they are responsible for the cognitive functionality of perception, consciousness, emotions, processing, etc.) (Crowder, 1999_4).

The ACNF Structure. The purpose of the ACNF is to:

1. Provide an architectural framework for “conscious” software agents.
2. To provide a “plug-in” domain for the domain-independent portions of the “consciousness” mechanism.
3. To provide an easily customizable framework for the domain-specific portions of the “consciousness” mechanism.
4. To provide the cognitive mechanisms for behaviors and emotions for “conscious” software agents.

Figure 3 illustrates the Cognitive Agent Framework that drives the agent coalitions that form memories, including emotional memories (Marsella, S., and Gratch, J, 202).

Artificial Neural Memories. The ACNF contains several different memory systems (including emotional memories), each with specific purposes (Newell, 2003):

1. **Perceptual Memory** – this memory enables identification, recognition, and characterization, including emotions.
2. **Working Memory** – contains preconscious buffers as a temporary workspace for internal activities.
3. **Episodic Memory** – this is a content-addressable associative memory with a rapid decay (very short-term memory).
4. **Autobiographical Memory** – long-term associative memory for facts and data.
5. **Procedural Memory** – long-term memory for learned skills.
6. **Emotional Memory** – both long-term (spatio-temporal) and implicit (inference) emotional memories.
Here we will discuss the use of emotional memories, as is the focus of the paper. The next section will discuss the use of Dr. Levine’s concepts to define artificial emotions based on Autonomic Nervous System States.

**Artificial Neural Emotional Memory and Emotional Learning**

**Emotional Memory Structure**

We know that memories are formed in a variety of systems that can roughly be divided into two broad categories: systems that support conscious memory (i.e. explicit memory systems) and systems that store information unconsciously (i.e. implicit memory systems). Memories about emotional situations are often stored in both kinds of systems (Cardinal, 2002). Figures 4 and 5 illustrate the basic structure for artificial emotional memories for AI systems. Figure 4 shows the structure for storage of emotional memories and Figure 5 illustrates retrieval of emotional memories.

![Figure 4 – Formation of Emotional Memories](image)

Figure 4 illustrates a high-level comparison of an artificial neural system with the human central nervous system. This provides the framework to map Levine’s Nervous System States into artificial system states that can be tied to artificial neural emotions.

**Emotional Event**

- Sensory System
  - Explicit Memory System (Spatio-Temporal Memory)
  - Implicit Memory System (Fuzzy Inference Engines)
  - Memories About Emotions (to Long-Term Memory)
  - Emotional Memories (to Associative Memories)

**Figure 5 – Retrieval of Emotional Memories**

Figure 6 illustrates a high-level comparison of an artificial neural system with the human central nervous system. This provides the framework to map Levine’s Nervous System States into artificial system states that can be tied to artificial neural emotions.

![Figure 6 – Comparison of the ACNF Connections with the Human Central Nervous System](image)

This, combined with cognitive emotional software agents provide the constructs for artificial emotional control, as illustrated in Figure 7 (Damasio, 1994). Combined, these provide the processing and intelligent agent environment to allow artificial neural emotions and emotional learning within an artificial intelligent processing system. The next section provides mathematical constructs for the notion of emotional learning.

**Emotional Learning**

In the ACNF environment, Drives, Priorities, and Constraints (see Figure 8) influence emotions. The behavioral subsystem receives situations and computes actions, while memories provide personality parameters and the various conscious agents’ sensitivities to emotional computation. If the cross-connectivity of the neural layers is considered as a matrix, we can compute emotional response from the column-wise fuzzy weightings (based on Dr. Levine’s Autonomic Nervous System States) and the action response from the row-wise fuzzy weightings.

It is assumed that each matrix element $E_{a,j}$ represents an emotion. $Emotion(a,j)$ of performing action $a$ in situation $j$. 

![Figure 7 – ACNF Emotional Learning and Memory Connectivity](image)
Given this, the genetic learning agents perform an emotion learning procedure, which has four steps:

State $j$: choose an action in situation – (let it be action $a$; let the environment return situation $k$).
State $k$: feel the emotion for state $k – \text{emotion}(k)$.
State $k$: learn the emotion for $a$ in $j – \text{Emotion}(a,j)$.
Change state: $j = k$; return to 1.

This learning procedure is an emotion secondary reinforcement learning procedure. The learning constraint used in step 3 is:

\[
\text{Emotion}^0(a,j) = \text{genome}^0(\text{inherited})
\]
\[
\text{Emotion}^1(a,j) = \text{Emotion}^0(a,j) + \text{emotion}(k)
\]

This learning rule adds the emotion of being in the consequence situation, $k$, to the emotion toward performing action $a$ in situation $j$ on which $k$ is the consequence.

**Artificial Autonomic Nervous System States and Neural Emotions**

Just as the amygdala and hippocampus are involved in implicit and explicit emotional memories, respectively, the ACNF and the cognitive perceptron coalitions become emotionally aroused when they form semantic and episodic memories about situations that cause “stress” within an artificial neural system (Davis and Whalen, 2001). Stress situations may involve a loss of resources, new data environments that are unfamiliar or new interfaces that are introduced into the environment. These cognitive representations of emotional situations better referred to as memories about emotions rather than emotional memories (Holland and Gallagher, 2004).

In human emotions, emotional arousal often leads to stronger memories (Dolan and Vuilluemer, 2003). This is a statement about explicit memories involving emotional situations (memories about emotions). The statement is unquestionably true, but there are two important caveats. First, while emotional experiences often produce very powerful and vivid memories that are easily recollected, the memories are not more accurate in their details than non-emotional memories (Phelps, 2006). This notion of the power of emotional memories can be useful in artificial neural system to allow rapid retrieval of memories and the situations that caused the memories (Dudai, 2004). This may be useful in the formation of self-healing constructs for integrated system health management to provide information sharing across system elements as to ways of dealing and handling system problems.

The effects of emotional arousal on explicit memory are due to processes that are secondary to the activation of emotional processing systems in the ACNF (Labar and Cabeza, 2006). For example, in a situation of danger (say in an artificial neural system controlling a weapon system), processing of threatening environment stimuli would lead to the activation of the active cognitive emotion agents within the ACNF, which, in turn, would transmit information to neural structures within the infrastructure of the system and system network. Activity in these areas would be detected by the cognitive coalitions and would lead to increases in system emotional arousal (due to activation of modulation within the neural structure that leads to the release of cognitive problem, solution, search, and emotion agents (see Figure 3). The transmittal of informational content as well as emotional context allows information retrieval performance to be greatly enhanced, allowing for “cognitive economy” within the artificial neural systems (LeDoux, 1996, 2000, and 2002). The next section describes the emotional states allowed within the ACNF and thus the creation, release, and then deactivation of cognitive agents within the overall cognitive framework. These emotional states are provided within the Autonomic Nervous System States described by Dr. Peter Levine.

**Artificial Autonomic Nervous System States**

Figure 9 illustrates the Autonomic Nervous System States described by Dr. Levine. The descriptions provided are put within the context of artificially intelligent system within an ACNF. These descriptions are “fuzzily” encoded within the cognitive inference engines. These provide the artificial neural emotional states that correspond to system states and stored, along with data and information to allow rapid retrieval and transmittal within the overall cognitive framework when similar situations present themselves for analysis and problem solving.
Artificial Autonomic System State Descriptions.

0: Base State: System is calm, current cognitive agents can easily respond to input (external interfaces). The artificial neural system is in a state of Pendulation (the artificial neural system’s natural rhythm supporting the basic process of contraction and expansion of system resources, corollary is the movement between tension and relaxation or inhalation and exhalation in human autonomic systems).

1: Mild Stress: Active, heightened state of cognitive awareness. System will allocate an increased number of cognitive agents in order to solve the current situation. Actual evolution takes place in this state as the cognitive framework collects information and makes inferences. Inferences about the emotions connected with the situation are categorized and stored in recurrent associative memory, while the informational content is stored in spatio-temporal memories. Short-term emotional responses are stored in the non-recurrent associative memory for processing by cognitive analysis agents.

2: High Stress: A hyper-alert, panicky state that in humans provokes fight or flight responses. In the artificial neural framework, it invokes a massive creation of cognitive solution (inference) agents as well as a massive increase in messaging agents to broadcast the emotional situation and information to as large a population of cognitive coalitions as possible. This promotes rapid thoughts and evolution of agents, and causes rapidly changing and extreme artificial neural emotions. This happens in an extreme situation where the system is in jeopardy of mission failure or shutting down completely. In this state it will consume large amounts of system resources. Emotional memory will include and predict the need for system resources required for problem solving should the situation arise again.

3: Mild Trauma: The heightened feeling of panic and hysteria (in neural system terms) is still present, however it is now an underlying emotion and the system appears to be in a dormant state, not able to find a solution to the problem at hand. It human terms, this state is appropriate for a situation that might need to be passive emotions, i.e., after a trauma when it is important to rest and gather one’s energy for a sudden outburst. In the ACNF, this is facilitated through an increased burst of genetic algorithms that search every possible solution space in order to provide an evolved solution that was previously unavailable and then allows a sudden burst of activity provide mission solutions.

4: Severe Trauma: The artificial neural system is perceived dormant or shut down. There is a lack of cognitive activity and emotional agents are suppressed in this state. There are eruptions of activity like those in State 3 and flashes of extreme evolution similar to State 2. This state is appropriate when the perceived threat to the system (either internally or externally) is overwhelming. This may occur in the ACNF when all external interfaces are unavailable and the system is devoid of input and no solution is imaginable within the current emotional and information states within the system memories. This causes a disconnection of the cognitive agents from its current emotional memory and a flurry of evolutionary activity is required to allow solution spaces to be evolved without emotional influence that could interfere with the evolution of a possible solution space. When solutions are available, neural connectivity to the rest of the system is reestablished and a new set of neural emotions and emotional memories are established and new neural pathways are established and “remembered.”

Conclusions and Discussion

The use of Emotional Memories within the Artificial Cognitive Neural Framework provides the constructs and mechanisms for rapid retrieval of memories as well as rapid broadcast of contextual information unavailable with non-emotion based neural systems. This paper described the framework and constructs, but there is much work left to do in this investigation. The possibilities are endless and the potential is for this work to radically change how we think about artificially intelligent systems and how the interact with the world.

References

3. Crowder, J., Barth, T., and Rouch, R., “Evolutionary Neural Infrastructure with Genetic


