Emotional Advantage For Adaptability and Autonomy

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ABSTRACT
During the last two decades, researchers have collected a decisive amount of experimental evidence about the fundamental role of emotion on cognitive processing. Emotional phenomena have been correlated with effective decision-making processes, memory, learning and other high-level cognitive capabilities and skills (e.g. risk assessment). In this paper we will describe an ongoing work that aims to design new Agent Architectures influenced by what has been learned in psychology and neurosciences about emotion-cognition interaction. In particular, we will present an agent architecture that includes several emotional-like mechanisms, namely: emotional evaluation functions, emotion–biased processing, emotional tagging and mood congruent memory. These emotional-like mechanisms are intended to provide agents with increased performance and adaptability in real-time environments. We will also introduce Pyrosim, a MAS platform we have developed to serve as an appropriate test-bed for Emotional-based Architectures. Pyrosim simulates a forest fire in a complex 3D environment where agents must take decisions about multiple concerns related to team coordination for fire combat in real-time.

Keywords
Emotion, cognition, adaptability, simulation.

1.Introduction
After many years of being considered as undesirable "hot" noise in an otherwise cold and perfect rationality, emotions are now seen as a fundamental link on a much wider chain of cognition. In recent years researchers have gathered a substantial amount of experimental evidence about the sophisticated role of Emotional mechanisms in high-level in cognitive activities such as decision-making, learning, planning, risk assessment and creative problem solving [3, 10]. Researchers also identified clear relationships between emotions and the storage and coding of information in memory as well as the corresponding retrieval processes [8]. From the point of view of Artificial Intelligence, what is particular relevant in these recent findings, is the fact that they corroborate the not so recent hypothesis [11] about the functional role of emotion: emotions are evolutionary engineering solutions and they are fundamental requirement for human-like intelligence. The role of emotional mechanisms is, in fact, quite extensive and it can, sometimes, be related with very specific functionalities. First of all, Emotions represent important sources of information highly centered on the individual. Emotions reflect the degree of success of the individual (agent) in achieving its explicit and implicit personal goals, given its own capabilities over the environment. They can measure how well the individual is succeeding in the environment or, alternatively, how favorable is that environment to the individual, given its current goals and capabilities. In this way, emotions may be seen as evaluation mechanism through which an individual may receive feedback about his goal achievement's performance in its environment. This evaluation may then motivate the adoption of new goals or reprioritize current ones. Sadness and frustration are examples of how such evaluation can be materialized, regarding both external as well as internal conditions.

Secondly, emotional mechanisms work as information collectors, filtering relevant but often highly distributed data from multiple sources. This condensed information package can be afterwards much more conveniently manipulated than the original data during decision-making or planning processes. When solving everyday problems, trying to answer the question "How do I fell about this?", which involves the presence of at least one emotion, may guide an individual during his decision-making process. These "everyday problems" that we are used to deal with reasonable success, may sometimes be very complex to solve: they involve reasoning about multiple concerns (practical constraints, personal goals, social rules, moral standards) and they frequently have to be dealt with in real-time.

Additionally, researchers have clearly identified another major role of emotional mechanisms in cognition: emotions provide a global management over other cognitive capabilities and processes. Different emotional states favor distinct processing schemes or strategies, different ways of accessing memory or even acquiring information from the environment. For instance, sad moods usually promote systematic processing strategies, great care with details and deep analysis of acquired data, whereas happy moods favor heuristic processing strategies with intense use of pre-existent knowledge structures instead of freshly acquired ones [10].

As we will describe later, the existence of emotional mechanisms (both in humans and animals) may be explained from an engineering point of view. Emotional mechanisms have emerged from a long evolutionary path and have clear functional purposes in a wider view of cognition. They lead to increased adaptability and robustness for individuals (agents) operating in complex real-time environments with their (limited) set of capabilities.

Based on these ideas, we have started a project described in [6] that intends to study how emotional-like mechanisms, parallel to the ones we described, may enhance current agent architectures. In the next section we will present and analyze several important issues about emotion in Humans. We will try to generalize certain concepts and show how they can be applied to artificial agents. We will present the current version of our Emotional-based Agent Architecture and also Pyrosim, a MAS for forest fire combat simulation. Pyrosim creates a very complex real-time environment that is, in our opinion, an essential condition to test our Emotional-based Agent Architecture.

2.Taxonomy of Emotional Phenomena

Emotional phenomena can be subdivided in, at least, 3 different categories: *specific emotions*, *moods* and emotional *dispositions*. Divisions can be made according to the following criteria:

- Object/Antecedent: cause or pre-conditions that trigger the emotional phenomena;
- Intensity: how strong is the influence of the emotion on the agent;
- Duration: time span that includes the rise and fall of the emotional phenomena;
- Consciousness: whether the agent is conscious about the occurrence of the emotional phenomena.

It is important to make this division because, although all of these phenomena share a common functional logic and high-level model, they have distinct impacts on cognition. Thus, for now, we shall try to differentiate them as clearly as possible, without alluding to their functional role.

Specific emotions are, by definition, emotional phenomena that can be quite clearly differentiated. Although the exact of set of specific emotions is still an open debate among cognitive researchers [2], anger, fear, joy, surprise, disgust are usually considered part of that set. Specific emotions, as those we have just referred, have well-defined objects and are usually very intense. However, they normally occur over a reduced time span (some seconds or minutes). Because of their strong intensity the Agent normally takes clear conscious of its existence.

On the other hand, *moods* encompass a different set of emotional states such as pleasant/unpleasant, anxious/relaxed. Contrary to specific emotions, moods may have no clearly defined object or antecedent. Also, because they are normally less intense, they may remain unconscious to the agent for most of the time. Moods may be originated by an intense or recurrent occurrence of a specific emotion (e.g.: anxiety after several fearful episodes) or simply by environmental factors (e.g.: the weather). They may last for hours or even a few days. We will also include in this category states such as self-confidence and frustration, a choice that will be clear shortly.

Emotional dispositions (sometimes called *temperament*) represent yet another step regarding duration of emotional phenomena. Chronic anxiety and depression are examples of emotional dispositions. They may endure for several months or years but tend to be inactive most of the time. They are assumed to be partially influenced by genetics and may emerge early in life. Emotional dispositions have also been observed to emerge in patients who have been prescribed certain medication or have been subjected to neuro-surgery [1].

In the next section we will focus on the processes that trigger these 3 types of emotional phenomena.

3.The Process of Emotional Elicitation

Up to now, we have not yet considered how or when a given emotional mechanism is activated to influence other cognitive mechanisms. We shall now reflect upon what is known as *emotional elicitation*, the processes that stimulates a particular emotional phenomenon.

Emotional Elicitation is a matter that generates great controversy among researchers [2, 9]. The main issue here regards the basic nature of elicitation process. Some researchers, mainly those coming from psychology field, advocate that emotional elicitation requires itself some form of high-level cognitive processing about the corresponding antecedents (appraisal theories [4, 7]). On the other hand, researchers coming from the neurobiology field [5] defend that some emotions can arise from lower form stimuli that do not involve any high-level cognitive circuitry (neocortex or hippocampus).

However, there is much less dispute around this question if a wider concept of "form of cognition" is considered, one that includes both high-level cognitive processes and also basic sensory information processing. From that perspective it is possible to gather the two contending views and reach a comfortable compromise. We will also adhere to this broader concept of "form of cognition", believing that it is possible to devise a general functional model of emotional mechanisms irrespective of the nature of their eliciting process.

As we have referred previously, emotions are deeply related to the evaluation of the agent own capabilities to achieve a defined goal. Goal, in this context, includes not only explicit formulations about desirable future states that the agent seeks to achieve but also implicit states that *must* be reached or maintained. In this context, emotions reflect the capability that the agent possesses (knowledge, action set, physical robustness, etc.) to cope with the current state of the environment in achieving one or more of his goals. This concept is known as *coping potential* [4] and is essential to a functional view of emotions. For instance, frustration *may* reflect a systematic inability to deal with the environment when trying to achieve a certain goal. Fear *may* reflect the fact that the current environment situation is highly unfavorable to the accomplishment of at least one *goal* (probably very important or even vital one), and that the agent does not have the needed capabilities to cope with the situation. It is interesting to note that fear is considered to have a very strong neurobiological / sensory dependency (the fear generated by the approaching of a fast object or by a high volume sound) but has also a highly cognitive dependency (the fear of a major inversion in the market share).

Therefore, and regardless of the nature of the eliciting process (cognitive or neurological), emotion elicitation involves the *evaluation* of the chances of achieving a given *goal*, taking into account both the state of the *environment* and the internal state of the *agent* itself. Emotional elicitation is then basically a *process of evaluation* involving: (1) a goal, (2) the current agent capabilities and its internal state, (3) an environment condition or event.

We will now try to formalize this concept in order to develop a general model of emotional mechanisms to be used in the emotional-like agent architecture we propose.

> **Definition 1:** The Emotional Evaluation Function (EEF) of a given goal (G) is a function that receives as inputs a vector <E>, containing the information perceived by the agent about the outside environment, a vector <I>, which contains information about the internal state of the agent, and returns a scalar value V that reflects the chances of the agent to achieve goal G.

$$V=EEF_G(<E>,<I>)$$

We impose no restriction about the nature of the Emotional Evaluation Function itself: it may be a simple algebraic function, mapping a combination of input values to a scalar output value (similar a neurobiological / sensory circuit) or it may quite possibly be a very complex inference or pattern matching procedure (similar to a high-level cognitive analysis). Still, we must emphasize that the evaluation always regards chances of agent achieving one of its goals, given its own (current) capabilities.

The Emotional Evaluation Function (EEF) is, however, a very general mechanism leaving much to be said about the process of evaluation itself. As we will demonstrate in the next sections, most of the modeling effort presented here is intended to provide a basic framework for developing agent with emotional-like mechanisms. The designer of agent must still decide many of the actual options of the framework (such as the own nature of the EEF) on a case-by-case basis. This should not be seen as a drawback because emotional mechanisms are, in essence, specific to agent goals, capabilities and, of course, the environment in which it operates. Some environment constraints, for example the need for a highly real-time response, may call for specific properties of the emotional mechanism (an anxiety-like emotional mechanism for instance) that might not be needed in a less demanding environment: the designer must always decide.

4.The Dynamics of Emotional Mechanisms

Previously, we have divided emotional phenomena in 3 different categories: *specific emotions*, *moods* and *emotional dispositions*. As we have also seen, they all involve some process of elicitation, although not necessarily of the same nature (cognitive vs. neurobiological). However, for each of those categories the duration of the elicitation process has a typical value. Angriness, which belongs to specific emotions category, may be elicited in just a few seconds (we all know that). On the other hand, depression, which can either be considered a mood or an emotional disposition, has usually much longer eliciting times. Additionally, the activity period of the elicited emotional phenomena does also vary for the 3 categories, ranging from a few seconds (specific emotions) to, eventually, many years (emotional dispositions).

The duration of the elicitation process and the activity period of the emotional phenomenon thereby elicited can be better understood according to two functional requirements of the response they motivate: *urgency* and *temporal consistency.*

Fast elicitation times are *functionally* appropriate when the eliciting condition is an event/situation that demands an *urgent response* from the agent. Note that this does not necessarily imply reactive response from the agent. It simply creates internal conditions to promote the appropriate answer (may it be breaking a car after detecting an approaching object or quickly constructing the appropriate verbal answer to an insulting comment). On the other hand, long elicitation times are compatible with the need to keep up with slow environment drifts or with recurrent events that do not pose an urgent demand on the agent but may have great influence in the long run. Regarding the activity period of the emotional phenomena, shorter activity periods seem appropriate when the response does not need to last, or may not be possible to sustain, for long periods. They are also usually related with specific event or condition that can be clearly identified in time. Longer activity periods seem useful when there is a need to cope with situations, possibly internal ones, which may be difficult to specifically identify or whose duration may be undefined. In these cases the agent should keep a *consistent response* over a longer (probably undefined) time.

In order to model this two-dimensional time behavior we shall introduce the concept of Emotional Accumulator [6].

> **Definition 2:** An Emotional Accumulator (EA_G) is a time (t) dependent process that incrementally stores a percentage ($P_{input,}$ - *Input Percentage*) of output value of one Emotional Evaluation Function, EEF_G.
>
> $$EA_G(t, P_{INPUT}, T_d)$$
>
> The value stored by an Emotional Accumulator decays exponentially with a specific time constant (T_d - *Decay Time Constant*).

Emotional Accumulators (EA) couple with Emotional Evaluation Functions (EEF) to build another element of our architecture, the Basic Emotional Structure (Figure 1). As we will show in the following section, it's through the use of Emotional Accumulators that these emotional-like mechanisms will influence other cognitive processes.

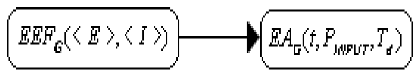

Figure 1 – The Basic Emotional Structure: Emotional Evaluation Function – Emotional Accumulator connection.

Emotional Accumulators provide the means to control the elicitation times and the activity periods of the Basic Emotional Structures. The P_{INPUT} (the *Input Percentage*) parameter controls the influence of the EEF in the increase of the accumulator values and the T_D parameter (the *Decay Time Constant*) will define how long the Emotional Structure stay active. Smaller values of P_{INPUT} will slow the elicitation times. Figure 2 shows a possible profile of the accumulator value.

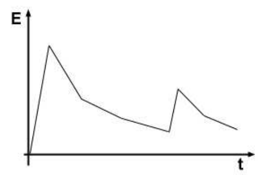

Figure 2 - Time behavior of an Emotional Accumulator. Increments represent updates from the coupled EEF. Accumulator value decreases at a rate specified by T_d.

Using the definitions of Emotional Phenomena from section 2 we can build the following table relating them with P_{INPUT} and T_D parameters values:

	P_{INPUT}	T_D
Specific Emotions	High	Low
Moods	Medium	Medium
Emotional Dispositions	Low	High

Table 1 – Ranges of P_{INPUT} and T_D parameters.

5.Emotion-Cognition Interactions

In the previous section we modeled the process of emotional elicitation by defining the Emotional Evaluation Function. We have also modeled the time behavior of emotional mechanisms by the means of the Emotional Accumulator. These were basic steps to establish a solid ground upon which we can develop our architecture further. However, we still need to consider the fundamental issue in our project: how will emotional-like mechanisms influence other processes?

At this point we must assume that the several building blocks of an emotionally enabled agent have a reasonable operating flexibility. This is a natural assumption since they are intended to operate in real-time on a dynamic environment. Therefore, these blocks may receive parameters that control their operating modes.

In this context, let us first consider a planning module that may have the following operating parameters: (1) *plan granularity*, (2) *maximum execution time*; (3) *available action set*; (4) *choice of the heuristics employed*.

Changing these parameters has, of course, influence in the resulting plan, but also in the computational effort employed. Parameters (1) and (2) control the computational effort of the planning process whereas parameters (3) and (4) have a great influence over the quality of the resulting plan. Any agent that possesses a limited amount of resources available (in this case time, computational power and action set) must correctly balance these parameters in order to optimize his response (in this case a plan) regarding a given goal. Emotional structures provide this balance, by evaluating the outside environment and the internal state of the agent, and sending this information directly to connected modules. The parameters available in the receiving module may then be inferred from the information sent by corresponding emotional structures (figure 3 depicts this relation).

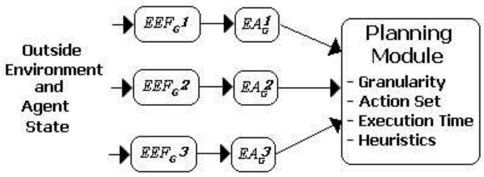

Figure 3 - An example of the influence of Emotional Structures on a cognitive process.

To see how these connections can be favorable to the agent let us suppose that Emotional Structures 1, 2 and 3 have emotional evaluation functions and emotional accumulators whose properties make them similar to those of the our well-known emotions *fear*, *anxiety* and *self-confidence*. For convenience we will label Emotional Structures 1, 2 and 3 as “Fear” “Anxiety” and “Self-Confidence”, respectively. For now, we will not explain how such Emotional Evaluation Functions can actually be implemented (rule-based, fuzzy logic, neural-nets, utility functions, etc.). We simply assume that they are able to evaluate both the outside environment and the internal state of the agent and subsequently produce the appropriate value: their actual implementation will always have to be pondered on a case-by-case basis. Let us first consider the influence of “Fear”. This structure should be activated whenever there is a condition that poses a great threat to one of the agent’s goals and requires an urgent response. The corresponding Emotional Accumulator should rise quickly and the Planning Module will receive its output. In order to cope with this immediate threat, the planning module may be readjusted in one ore more of its parameters in the following ways:

- Increase granularity. The agent needs a quick executing plan. A plan with fewer steps is eventually better.
- Reduce Action Set. Some actions may become inhibited and will not be considered during the planning process. This selection will possibly speed up the planning procedure (*action tendency* [4]).
- Limit the Execution Time. The Agent needs the plan as soon as possible so that the planning procedure can only last for a limited time. This may imply a global change in the planning strategy.
- Change the heuristic used in the planning procedures.

All these parameter variations seem to make sense from a functional point of view: they create the conditions for a rapid answer to a specific threatening condition. This answer should *probably* be close to the optimal one given the urgency of the situation, and also the limited resources the agent has available.

If instead of the “Fear” Emotional Structure, which is intended to deal with specific threatening conditions, we take “Anxiety” we may expect a different interaction. The “Anxiety” Emotional Structure should be activated whenever the overall situation is not favorable to the agent, although no specific threat exists at that moment. It can also be activated whenever there are suspicions of a possible conflict between two or more of the agent goals.

In such a situation one would expect the following changes in the planning module parameters:

- Decrease granularity and Increase the Depth of the plan. The resulting plan should have a reasonable degree of detail and should also be made in order to deal with situations during a medium/long time span.
- Increase the enabled Action Set. The planning procedure should explore all of the possibly actions of the agent. This may help the discovery of good opportunities or even other specific threats.
- Use conservative heuristics. The agent should be pessimistic about the outcome of his actions. This should result in safer plans.
- Increase the Execution Time. While possible, continue refining the plan. Planning stops when the agent encounters a urgent situation of a satisfying plan is found. In the last case, the “Anxiety” system will automatically be deactivated when it identifies this event.

According to these guidelines, an increase in the value of the “Anxiety” Accumulator will hopefully increase the quality of the produced plan, which allows the agent to deal with the unfavorable environment much better. However, there is a price we cannot ignore: a superior computational effort on the planning module that has to be made at the cost of processing time dedicated to other modules. For an agent with limited processing resources this needs to be carefully balanced: the agent cannot be always operating on this state. If there is a regular or persistent “Anxiety” state, there is strong evidence that the agent lacks the effective capacity to cope with the current environment. At that point, we may assume that this situation may activate yet another Emotional Structure, (e.g.: a frustration mood) in order to deal with this persistent incapacity to cope with the environment (e.g.: belief revision).

Finally, let us consider the influence of the "Self-Confidence" Emotional Structure in the behavior of the planning module. The "Self-Confidence" Structure should be activated whenever the agent has been having success in dealing with the environment. In such a situation, and given the limited processing resources of the agent, the planning effort should be diminished since the agent is having reasonable success and no close threats are expected. The unused computational power should then become available to other processes (possibly with lower priority) allowing the execution of other co-existing tasks (e.g.: pattern processing, data mining, neural-net training). To release computational power, the 4 parameters of planning module that we have been manipulating should suffer the following variations:

- Increase granularity. Only a high-level plan is currently needed.
- Select in the Action Set to the most recently used actions. Recent actions have proven to be successful so they should be preferred and considered firstly.
- Use optimistic heuristics. The agent is performing well it is conceivable that the environment is globally favorable. This may help the agent in finding exceptionally good opportunities (although maybe improbable).
- Decrease Execution Time. While the value of "Self-confidence" Accumulator is high seems natural not to spend too much time planning.

Again, all these changes look reasonable when seen from a resource management point of view. They help to release a significant amount of computational power that would probably not represent an advantaged to the agent if employed in the planning module. In a complex and dynamic environment this would be even more so, since a highly structured and computationally expensive plan could become invalid after a given change in the environment.

With this example we tried to demonstrate one possible case of interaction between a highly cognitive process (planning) and emotional-like mechanisms, putting in evidence their functional role. There would be many more examples relating emotional-like mechanisms with other cognitive processes such as sensory information analysis, state search, learning, risk-assessment, uncertainty reasoning, social interaction, or even specific actions.

It is now important to analyze again these interactions from a conceptual point of view. In this sense, emotional mechanisms can be said to have two fundamental functional roles: *providing and managing information* and *influencing the operating modes and processing strategies* of cognitive processes. We will address these issues in the next two sections.

6.Emotion and Information

6.1Emotion as Information Source

When real-time response to the environment is required there simply may not be enough time to thoroughly evaluate all relevant dimensions at stake. In complex environments, where the uncertainty or the indistinctness of such dimensions may be overwhelming to the agent, it may even be impossible to do so. In dealing with such situations, emotions have a tremendous informative power. For instance, when asked to rate their overall life satisfaction, people will not engender a complex multi-criteria evaluation process to answer this question: they will simply ask themselves "How do I fell about my life ?" [10].

This simple example illustrates the power of emotions in condensing information of several distributed sources into single units, the emotional states, which can then be conveniently used as signals to other cognitive processes.

Condensing information into a single emotional state can apparently seem an undesirable reality reduction, involving the risk of discarding important information. However, as we have seen before, the process of emotional elicitation involves an evaluation of the environment focused on goal success chances. Therefore, if the elicitation process is effective, the condensation will emphasize the existence of information relevant to one or more of the agent goals.

In this context we need to differentiate between the information conveyed by *specific emotions* and by *moods*. By definition, specific emotions should be able to supply information about a defined object that is relevant in the immediate situation (e.g.: fear of an loud noise). On the other hand, moods should be able to supply a much more generic information content. Moods carry information about the global success of the agent in achieving its goals, which is particularly valuable to higher order processes (e.g.: goal generation, personal evaluation).

In either case, feeding the emotional state information as direct input to cognitive processes can speed up those processes because it provides well-defined information to work with. Therefore, emotional information seems to be particularly useful when choices about actions that need to be performed quickly or whenever the available data is inconsistent or too complex to work with.

6.2Tagging and Mood-Congruent Memory

Besides this possibility of considering emotional states as direct information source to cognitive processes there are yet other important relations between emotion and information. Researchers [1,8] have established a very strong link between emotion and memory, a link that has several important functionalities associated.

The first of those functionalities is *emotional tagging* [1]. Instead of being simply stored in memory, information is first marked with an emotional tag, relating that information with the current emotional state of the agent. The tagging procedure is itself important because it allows selecting which information should be stored in long-term memory and which should be stored in short-term memory or simply discarded [6]. Usually, highly emotional events or facts are not easily forgotten and can be remembered for long periods: we all know this from our own experience. This reflects a functional need, as information collected during periods of intense emotional activity should, in principle, be highly relevant to agent's goals. Therefore, if we take into account that memory is a very scarce resource, emotional tagging and the corresponding information selection serves a very useful purpose: saving memory to store the most relevant facts to the agent. Figure 4 tries to illustrate how a tag is created.

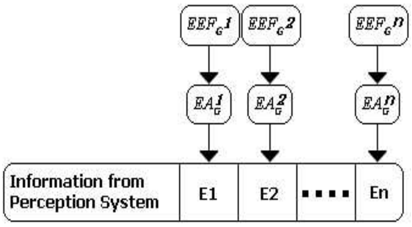

Figure 4 – An Emotional Tagging process in action.

Another important interaction between memory and emotion is a mechanism known as Mood-Congruent Memory (MCM) [8] that is deeply related with emotional tagging. It has been shown under a great number of circumstances that we tend to retrieve from memory information that is consistent with our current emotional state. In other words, information whose emotional tag is compatible with the current emotional state has a high probability of being recalled. Again, this may be interpreted from a functional point of view. Considering that events that produce similar emotional responses are probably correlated, bringing to working memory facts or beliefs that are coherent with the current emotional state may be useful in the current situation. Mood-Congruent Memory may help the agent in discovering interesting opportunities or possible threats in the current situation, based on its own past experiences. It may also simplify processes of decision by reusing knowledge acquired in similar past situations.

As we have briefly shown, interactions between memory and emotion suggest the existence complex yet useful mechanisms for dealing with real-time and dynamic environments. At the moment, we have already included the emotional tagging mechanisms in our architecture and we are studying possible models for including Mood Congruent Memory mechanisms. We believe that Emotion-Memory interactions look very promising for improving agent architectures and we intend to dedicate a great amount of effort in their study and modeling.

7.Emotion and Processing Strategy

In the last section we have focused on the interaction between emotional-like mechanisms and information. We have considered the role of emotion as information source and as memory management criterion. In this section we will concentrate on the effects of emotional-like mechanisms on the processing strategy employed by the agent cognitive modules.

We will start by making an observation about our own processing strategy alternatives. There have been identified 4 distinct processing strategies that establish different levels of interaction with emotional mechanisms [8]:

1. *Direct Access:* this is the simplest of the processing strategies that relies on the retrieval of pre-existent structures/knowledge to produce a result. Using rule based mechanisms or case-based reasoning to select an action are processes that fit in this category. Direct access is a minimum effort mechanism.
2. *Motivated Processing:* this strategy is employed when there is a defined goal that guides processing. This strategy is used when searching knowledge for a suitable answer or in the production of a plan to achieve a given objective.
3. *Heuristic Processing*: it is used to deal with situations that may not have a clearly defined objective or whenever there is not sufficient information or cognitive capacity available. Heuristic processing is also a minimum effort strategy.
4. *Substantive Processing*: this is the most complex information processing strategy. It is employed when people learn, interpret and need to perform association, or in general, when tasks are complex or atypical.

Recalling the previous section, Direct Access and Motivated Processing strategies are relatively immune to usage of emotional information: they operate systematically on objective data about the environment. On the other hand, heuristic and substantive processing rely deeply on the information generated by emotional mechanisms and can be seen as more personal/introspective strategies that handle possibly fuzzy situations.

Another important distinction between these processing strategies is related with the amount of processing power needed. Direct Access and Heuristic Processing are the least expensive of the 4 processing strategies requiring minor processing power. However, Motivated Processing and Substantive Processing are associated with complex tasks such as planning, learning, interpreting, judgment, etc that require significant computational power. Figure 5 shows the relative position of these 4 processing strategies regarding the use of emotional information and computational power required.

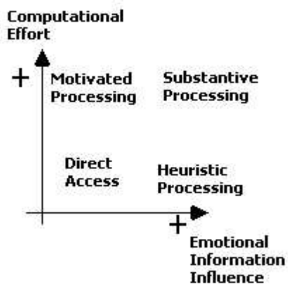

Figure 5 – Relative position of the 4 processing strategies regarding Computational Effort and Influence of Emotional Information

Some of the tasks associated with a specific processing strategy can occur simultaneously as long as there is enough computing power available. In some cases, a certain task will require most of the available processing power (e.g.: planning, pattern matching, learning) so that other concurrent tasks must be must be computed in less expensive ways. For a resource-bounded agent, it is important to optimize the way these 4 processing strategies are balanced and combined and how concurrent tasks should be computed.

There is a significant amount of experimental evidence that emotional states have a decisive influence over the selection of processing strategies. It has been shown [10] that positive moods, such as happiness and self-confidence, favor the choice of heuristic or simplified processing strategies. In these emotional states, people tend to rely on preexistent or generalized knowledge structures (e.g.: stereotypes [3]) to make specific decisions and judgments, and also tend to employ top-down and high-level approaches to solve a particular problem. This would be compatible with the use of *Direct Access* and *Heuristic Processing* strategies in positive moods. On the other hand, people who are in a sad or other negative mood tend to adopt a more systematic processing style, with great care for details and current environment information, and bottom-up approaches. This style is compatible with *Motivated Processing* and *Substantive Processing* strategies.

As we have seen, these two alternatives differ significantly in the processing power they require: Direct Access and Heuristic Processing are reasonably computationally inexpensive whereas Motivated Processing and Substantive Processing will certainly consume most of the processing power available. However, from a functional point of view, there is a strong coherence between the emotional state, the processing strategy and the amount of resources required to support that same strategy. Negative moods indicate that the agent is not having success in achieving its goals and it is facing problematic situations. Systematic processing styles, detailed analysis of environment information and bottom-up approaches, such those as used in Motivated Processing and Substantive Processing, may be much more effective, and payoff the extra computational cost. Conversely, when the agent is having success in coping with the environment, a fact that should be signaled by positive moods, less expensive processing strategies will be promoted: Direct Access and Heuristic Processing. These strategies will make use of pre-existent routines and knowledge that, as signaled by the emotional state, have proven to be effective before.

By using these simpler processing strategies, whenever the environment is signaled as favorable, the agent can free up a given amount of processing resources. However, for a resource-bounded agent that operates in complex environments all processing power is valuable and should not be wasted. The agent should re-allocate the unused processing resources to non real-time or lower priority tasks that may also be important in providing long-term adaptability (data-mining, inference of new rules, pattern detection, etc). If, somehow, the agent starts failing to cope with the environment, a negative emotional state should be elicited that will then promote the reorganization of the processing strategy.

This processing resources management scheme, which makes use of the emotional state a clue, seems a powerful and cost effective adaptation tool. It allocates just enough processing power needed to solve the current situation while supplying the reminding processing resources to other mechanisms responsible for long-term adaptation. This illustrates once again the functional role of emotion that we seek to explore and include in agent architectures.

8.The *Pyrosim* Environment

In order to test the validity and utility of these concepts we decided to use simulated environments to test the performance of emotional-based Architectures. We began developing agents for the RealTimeBattle environment (available on http://www.realtimebattle.org) that simulates a battle arena where agents combat each other for survival. The experiments made using RealTimeBattle allowed us develop a sharper understanding about emotional-like structures, namely Emotional Evaluation Functions coupled with Emotional Accumulators [6]. They also made possible to validate some of our initial ideas about the functionalities of emotional-like structures, in particular in biasing the dominant behavior of the agent (*action tendency*). However, we soon realized that to effectively test other emotion-cognition interactions (e.g.: Mood-Congruent Memory and Processing Strategy management) we needed a more complex simulated environment that would impose higher demands on the Agent. Simple environments do not reveal the need for emotional-like mechanisms. After some research aimed to find a suitable environment simulation to test emotional-based architectures, we chose to build one from scratch especially dedicated for our needs. In order to be an appropriate test-bed for emotional-based architectures, the main requirements for this simulation environment considered were: (1) high level of complexity for the participating Agent; (2) real-time demands, and highly dynamic; (3) multiple concerns at stake; (4) multi-Agent System; (5) closeness to a real-world problem.

Based on all these requirements we decided to develop a forest fire environment simulator, the *Pyrosim*. This simulator supports multi-agent efforts and imposes several low-level and high-level demands on each agent. Each individual agent can combat fire cells with a water jet connected to a limited capacity water tank. Agent mobility is constrained by its own simulated physical capacities (energy and acceleration) as well as by limitations imposed by the terrain and the fire. Fire propagation through the terrain, depends on the vegetation type and density, the terrain slope, and the wind, based on a realistic model. Agents may communicate using radio or voice to coordinate their task. There are some special locations in the map whose importance is higher (housing, factories and natural resources) and must be carefully protected by agents. This condition demands from the agents an efficient priority and goal management scheme.

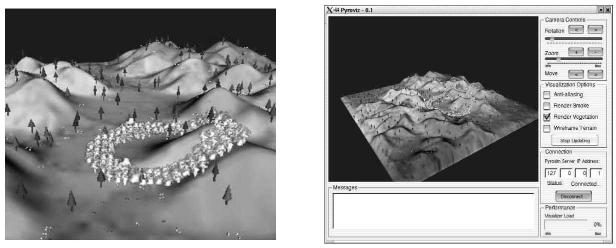

Figure 6 - A view of the simulated environment and the visualizer application user interface.

In a complex environment such as Pyrosim, which demands real-time response from the agent, we believe emotional-like mechanisms will play an essential role. Thus, it seems useful to include in agent design the following Emotion Structures (among others):

"Fear": specific emotion that will be elicited whenever a dangerous or uncontrollable condition (temperature too high or fire too close) or is detected or whenever the agent is in a place similar to where previous damages were suffered. The agent should employ a *Direct Access* processing strategy.

"Anxiety": specific emotion (or mood) should be elicited when the agent faces a possibly difficult situation (e.g.: running out of water low, fire front approaching a important resource). A *Motivated Processing* strategy should be preferred.

"Self-Confidence": mood elicited as a result of a successful performance. A "Heuristic Processing" strategy should be employed. Released processing time should be used to discover new relations (e.g.: inferring new rules), develop new capabilities (e.g.: training neural nets) or analyzing past events (e.g.: pattern matching, data mining). Agent will tend to have an optimistic behavior and select more risky actions.

“Frustration”: contrary to “Self-Confidence”, it will be elicited when the agent is not coping well with the environment. It should activate introspection processes (e.g.: knowledge revision, rule validation, etc). Either a Motivate or Substantive Processing Strategy should be used.

As far as Mood-Congruent Memory is concerned, running multiple rounds of simulation will allow us to test and refine our models. Agents will be able to recall the most significant events and data that they have emotionally tagged and selected from previous rounds.

These are only some examples of the ideas we intend to test using the Pyrosim simulator. We are currently refining Pyrosim while we build and test new Emotional-based Agents. We believe Pyrosim will become an interesting test-bed for Emotional Architecture.

9.Conclusion

In this paper we have presented an ongoing project that is developing deeper insights about the functional role of emotion and its use in Agent Architectures. We have tried to formalize several concepts regarding emotion (*specific emotions*, *moods*, *emotional dispositions*) and associated phenomena (*coping capacity*, *evaluation*, *elicitation*). We have introduced the key elements of our emotional-based architecture, namely the *Emotional Evaluation Functions*, the *Emotional Accumulators* and the *Emotional Structure,* a higher order compound that connects the former two. We gave examples of how emotional mechanism may interact in a functional way with cognitive processes, and showed how that interaction may be a significant advantage for an agent that operates in a complex environment. Also, we have developed a formal description of the interactions between emotion and cognition regarding the importance of emotion on the information available to the agent and the effect of emotion on processing strategies. Finally, we have presented Pyrosim, a fire combat simulation environment designed to support the development of Emotional based Architectures and pointed the future research paths.

10.Bibliography

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