Using Motives and Artificial Emotions for Prolonged Activity of a Group of Autonomous Robots

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Abstract

To operate over a long period of time in the real world, autonomous mobile robots must have the capability of recharging themselves whenever necessary. In addition to be able to find and dock into a charging station, robots must be able to decide when and for how long to recharge. This decision is influenced by the energetic capacity of their batteries and the contingencies of the environment. To deal with this temporality issue and using research evidences from the field of psychology, this study investigates the use of motives and artificial emotions to regulate the recharging need of autonomous robots.

Introduction

Maslow's Hierarchy of Needs Theory recognizes physiological needs (hunger, thirst, breathing, sleeping, etc.) as the most basic ones for human. For a robot, this means to have energetic autonomy.

To conduct experiments that allow robots to autonomously recharge themselves, a charging station that they can find and use is required. It is possible to emulate autonomous recharging by having the robots go to a specific location and have somebody replace batteries or manually plug the robot to a power supply. But situations such as a potential malfunction or sharing access to the charging station cannot be completely addressed.

Another important aspect related to energetic autonomy is to decide when and for how long to recharge: the robots may need to recharge when they are accomplishing a critical task; charging stations may already be in use and many robots may be waiting to use them; it may be difficult to anticipate how long it will take to find a charging station and how much energy is remaining, etc. In dynamic and unstructured environments like in the real world, efficient adaptation to these constraints is required by the robots. In fact, this is related to what have been qualified by Plutchik (Plutchik 1980) as the problem of temporality, one of four universal problems of adaptation. Temporality "refers to the fact of the limited duration of an individual's life" (Plutchik 1980). Plutchik also suggests that "emotions are reflections of the adaptations that animals make to the universal problems". Based on this idea, this research investigates the use of motives and artificial emotions to regulate the recharging needs of autonomous robots working in a group.

Artificial Emotions

What are emotions? Surely trying to answer this question is not without experiencing a variety of emotions! A survey of different definitions is given in (Strongman 1987), and for the sake of generality, here is the definition of Kleinginna and Kleinginna that tries to put everything together in one all-embracing definition:

> Emotion is a complex set of interactions among subjective and objective factors, mediated by neural/hormonal systems, which can (a) give rise to affective experiences such as feelings or arousal, pleasure/displeasure; (b) generate cognitive processes such as emotionally relevant perceptual effects, appraisals, labeling processes; (c) activate widespread physiological adjustments to the arousing conditions; and (d) lead to behavior that is often, but not always, expressive, goal-directed, and adaptive.

From this definition, we can understand why a lot of theories has been developed about emotions, and still no complete theory of emotion exist (Rimé & Scherer 1989).

The concept of artificial emotion is increasingly used in designing autonomous robotic agents, mostly by making robots respond emotionally to situations experienced in the world or to interactions with humans (Velásquez 1998; Breazeal 1998). But it seems that there is more to it than that. Psychological evidences suggest that they can serve three important roles in designing autonomous robots (Michaud *et al.* 2000):

- *Emotion to Adapt to Limitations*. Emotion plays a role in determining control precedence between different behavior modes, coordinating plans and multiple goals to adapt to the contingencies of the world (under constraints of time and other limited resources), especially in imperfectly predictable environments (Frijda 1987; Oatley & Johnson-Laird 1987; Plutchik 1980). Uncertainty prevents any complete dependence on predictive models in human planning – people typically think only a step or two ahead and they respond, moment-by-moment, to the new arrangements of the environment that their actions help to create (Oatley & Johnson-Laird 1987). The adaptation problems that emotion help solve are finding an equilibrium between the subject's concerns and the environment by signalling the occurrence of concern-relevant events, by recognizing the plan junctures that these events imply, and by instigating control shifts accordingly (Frijda 1987).

- *Emotion for Managing Social Behavior*. In relation to social behavior, Plutchik (Plutchik 1980) interestingly points out that emotions are in direct association with four **universal problems of adaptation**, which are: **hierarchy** (Anger/Fear), **territoriality** (Exploration/Surprise), **identity** (Acceptance/Rejection) and **temporality** (Joy / Sadness). Plutchik's theory also suggests the possibility that emotions "are functional adaptations for establishing a kind of social equilibrium. This would imply that emotions enter into every social transaction and help to establish a balance of opposing forces. These balances are always temporary and frequently change as we move through life from one conflict to another" (Plutchik 1980). This is also suggested by Oatley and Johnson-Laird (Oatley & Johnson-Laird 1987), especially in the context of creating mutual plans: "Mutual plans cannot be innately wired into the cognitive systems; they must be created in the minds of more than one individual by implicit or explicit agreement." These plans are partly under the control of both participants and partly governed by conventions of their society. One way to set up a mutual plan is to make a promise to somebody, creating an obligation and a corresponding expectation. Emotions are then used to communicate junctures in mutual plans among individuals in social groups.

- *Emotion for Interpersonal Communication*. In order for emotions to regulate behavior in social interaction, emotion also has a communicative role, as suggested in the previous paragraph. Ethologists believe that emotional expression have a communicative function and act as releasers for the coordination of social behavior. There are signals that promote group cohesion, signals to communicate about external environment, and intraspecific threat signals. It is to an animal's advantage to communication its intentions, and to be sensitive to such messages from others (Mook 1987). Emotional expression promotes individual isolation (as it may be necessary in defending something) or to promote group (as different social circumstances might require). In fact, the role of expression in emotion can be seen from three different views: the situation is evaluated by emotion that lead to an expression; expression may be a reaction to the situation that also produces the emotion; the expression may affect the emotion rather than the other way around (Mook 1987). Emotion then serves a dual purpose: it is a communication act and it is a sensed state.

Trying to summarize the various theories surrounding the notion of emotion, we could say that: (1) emotions are causes of action; (2) cognition can trigger emotions – emotions can trigger cognitive operations; (3) emotions can cause expressive actions; (4) emotions can affect purposive, goal-directed action; (5) emotions can become goals; (6) the behavior also affects emotion (Mook 1987). One interesting aspect is that emotional experience is the cause of emotional behavior, and the emotional experience is also response: it occurs in parallel to behavior and is part of its causes (Rimé & Scherer 1989).

From an engineering point of view, autonomous robots would surely benefit from having mechanisms that play a similar role. One possibility is to use internal variables that have the same purposes as emotion, as outlined in the previous paragraphs. In addition, different mechanisms for implementing artificial emotions can surely be designed according to properties associated with the decision making approach used to control the robot. Taking all of this into consideration, our long term research goal in this project is to propose a model of artificial emotion that is suitable for the architectural methodology used in our research, and see how it can help a group of robots behave autonomously in its environment. But before we can do that, we have to address other aspects related to the capabilities necessary for making robot manage their energy autonomously, and these aspects are described in the following section.

Architectural Methodology, Motives and Artificial Emotion Model

We program our robots following the guidelines of a hybrid reactive-deliberative architectural methodology (Michaud, Lachiver, & Le Dinh 2001; Michaud & Vu 1999) that allows to combine various properties associated with intelligent behavior, like reactivity, reasoning and motivation, while still preserving their underlying principles. The architecture is shown in Figure 1 and is built on top of behavior-producing modules connecting sensory information to commands. To summarize briefly, *Behaviors* are selected dynamically according to influences coming from *Implicit* conditions determined only by sensory inputs, from a hierarchical organization of the goals of the robot (managed by the *Egoistical* module), and from reasoning done by the *Rational* module using knowledge innate or acquired about the task. Note that information can be exchanged between the *Rational* module and the behaviors. Processes for these three modules all run independently and in parallel to derive behavior recommendations *d/u*, i.e., behavior *desirability/undesirability*. This ensures that emergence is also preserved for the selection of behaviors. The *Behavior Selection* module simply activates behaviors that are more desirable than undesirable.

In our proposed artificial emotion model, *Emotions* are there to monitor the accomplishment of the goals of the robot over time, and these goals are represented using *Motives*. These abstractions are presented in the following subsections. Before explaining them in more details, note that one important source of information for motives is the observation of the effective use of the behaviors, which can serve as an abstraction of the robot's interactions within the environment. This last influence is related to the link called *Behavior.Exploitation*. An active behavior may or may not be used to control the robot, according to the sensory conditions it monitors and the arbitration mechanism used to

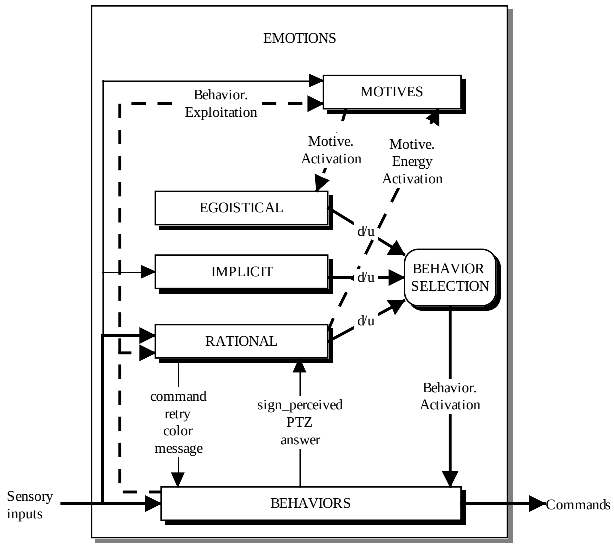

Figure 1: Architectural methodology.

coordinate the robot's behaviors. So, an active behavior is exploited only when it is releasing commands that actually control the robot.

Motives

Works on motivational systems (Maes 1990; Breazeal 1998) have shown that a good balance between planning and reactivity for goal-management can be achieved using internal variables that get activated or inhibited by different factors. So we use a similar approach for motives. Each motive is associated with a particular goal of the robot. The word 'motive' is used because it refers to something that prompts an agent to act in a certain way. The activation level of motives are used by other modules of the architecture to affect the overall behavior of the robot. As shown in Figure 2, a motive m is characterized by an energy level E and a mapping function M that are used to determine its activation level A, according to the formula: $A_m = M(E_m)$. The energy level and the activation level of a motive range between 0 and 100%. The energy level can be influenced by various factors: sensory conditions, exploitation of behaviors associated with the motive, activation of other motives, *Rational* influences, emotions, and time. The energy level is computed by the equation $E_m = \sum_{j=1}^{n} w_j \cdot f_j$, where f represents the occurrence of n influencing factors, weighted by w, affecting the motive. This equation can also be interpreted has having different increment or decrement values w associated with particular events n. The influences are computed every processing cycles, i.e., at 10 Hz. For factors that occur for long period of time and that must not influence the motive for the entire period, we use a habituation function (Staddon 1993) to modulate its influence. Equation 1 presents the habituation strength $h(t)$ calculated for an input j, and α represents the habituation rate. The habituation strength is used to modulate the weighted input that influence the energy level of the motive. With a higher habituation rate, the same weighted input has less influence over a consecutive period of time. Finally, mapping from E to A can be directly transposed, determined using thresholds, or triggered according to the energy level of other motives.

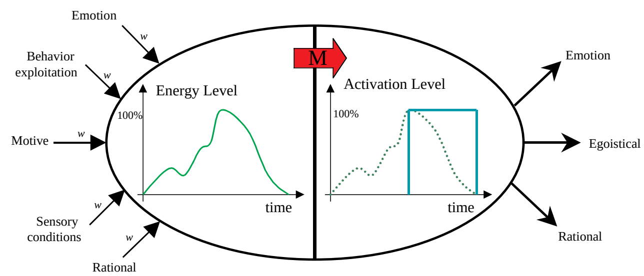

Figure 2: Schematic representation of a motive.

$$v(t) = (1-\alpha) \times (w_j \cdot f_j) + \alpha \times v(t-1)$$
$$h(t) = (1-\alpha) + \alpha \times v(t-1) \qquad (1)$$

In the case of the recharging need of the robot, the motive named *Energize* is used to decide when and for how long recharging is required. The activation level of *Energize* is derived from the energy level using a linear mapping function, i.e., the activation level equals the energy level. The *Needs* module examines the activation level of this motive to recommend the use of behaviors, like the *Recharge* behavior that makes the robot find and dock to the charging station, according to the following rules:

- If the activation level of *Energize* is greater than 50%, the *Recharge* behavior is desired. The *Recharge* behavior makes the robot dock into the charging station when it is perceived.
- If the activation level of *Energize* equals 100%, behaviors that might interfere with the detection of the charging station are set to be undesirable. Other behaviors that might help in finding the charging station, like *Follow-Wall*, are set to be desirable.

When the robot is not docked to the charging station, the energy level of *Energize* is influenced by the following factors:

- Battery voltage level. The voltage level of the batteries does not decrease by a fixe amount over time. So the amount of energy left can only be roughly approximated by looking at the voltage level over time. We observed that our robots have an autonomy of approximately 2 hours in movement with their batteries fully charged, and 4 hours if they remain still.
- Sensing of the charging station. The robot has the capability sensing the presence of the charging station. In that case, the energy level of *Energize* is incremented by 0.05% but weighted by a habitation with $\alpha = 0.6$. The habituation effect on this signal avoids constantly increasing the energy level of the motive during the time the robot is perceiving the charging station. Combined with the decision mechanism used by the *Needs* module to recommend

behavior, the robot can opportunistically use the charging station if the energy level of *Energize* is sufficient.

- *Rational* module. Depending on the task and on commands given by a user, this module may increment or decrement the energy level of *Energize* to make the robot recharge its batteries before starting to accomplish a long task or to allow the robot to complete a critical task before it goes recharge.

Once docked, the robot must decide how long it should remain on the charging station. Using the voltage level is not appropriate to determine when the batteries are sufficiently charged, because the voltage level is influenced directly by the charging station. First, the voltage level rises quickly, and then slowly stabilizes. Also, our charging station optimizes the charging process by considering the amount of current generated by the power supply, and this also influences the voltage level readings of the batteries. So, what we need to do is to let the robot remain long enough to get its batteries charged, but to be ready to leave as soon as possible when sufficient energy has been accumulated and let others use the charging station when necessary.

To determine the amount of time to remain at the charging station, the energy level of *Energize* is used to approximate the maximum time required for charging. Our approach is simply to decrement the energy level of *Energize*, using the energy level as an approximation of the amount of recharging required. When it is low, the robot needs to recharge for a shorter period than when it is high. Our charging station is able to recharge the batteries of a robot in 2 hours. We empirically set a decrement value of 0.001% when the energy level is greater than 50%, and of 0.003% otherwise. The first phase is to give a minimum time of 83.33 minutes for the robot to recharge its batteries without being allowed to leave. The second phase uses a greater increment because when the robot is not recharging, the *Recharging* behavior is not activated on this interval of energy level of *Energize*. This signifies that the robot has sufficient energy to operate, and if the robot finds the charging station not long before having activated *Recharging*, it will stay less time on the charging station (27.78 minutes for this second phase). This allows the robot to continue doing tasks that got interrupted when it opportunistically found the charging station. These values were found empirically and work fine in our experimental setups.

Artificial Emotion Model

As shown in Figure 1, the emotional capability is incorporated into the control architecture as a global background state, allowing emotions to influence and to be influenced by all of the architecture's modules. This is to take into consideration the multiple effects emotions can have on the behavior of the system. In our design, emotions can be used to change some of the parameters of behaviors, adapting the way the robot response to stimulus. They can also change the goals pursued by the robot. This is related to research conducted by Oatley and Johnson-Laird (Oatley & Johnson-Laird 1987), indicating that emotions provide a biological solution to certain problems of transition between plans in systems with multiple goals and in unpredictable environments, by maintaining these transitions and by communicating them to ourselves and to others.

In addition, our goal is to derive an emotional model that is generic and not specifically configured for a particular task. We would like the mechanisms that derive emotional states to be the same whatever the goals pursued by the robot. For instance, we try to avoid making a direct influence with an emotion like pain and the event of having the robot collide with an obstacle: in some cases making contact with an object may be desired. So such influences cannot be valid in all situations, and a cognitive approach (Strongman 1987) to emotion (via the *Rational* module) would allow to specify explicitly what influences can be considered in specific conditions. For our research and trying to complement other research works on artificial emotion, we are interested in finding a model that allow emotions to be influenced by all possible situations, and not specifically to particular states and conditions. Also, the model of emotion we proposed to study differs from other emotional representation in that the behavior of the system is not oriented toward satisfying particular emotional states. In our model, the energy level of motives is used as an abstraction of the progression toward the accomplishment of the goals associated with activated motives. Monitoring the energy level of motives makes the approach generic, since the emotions can be used in different contexts (i.e., goals) according to the motives activated and their priority. Note that we are not excluding in the future the possibility of having direct influences on emotions, instead of only relying on the analysis of energy level of motives.

More specifically, the model is a two-dimension bipolar model with four emotions: *Joy/Sadness* and *Anger/Fear*. *Joy* and *Anger* are positive emotions, while *Sadness* and *Fear* and negative emotions.

- *Joy*: monitors a decrease in the energy level, indicating the accomplishment of the goal associated with the motive.
- *Sadness*: monitors an increase in the energy level, indicating difficult progress in the accomplishment of the goal associated with the motive. A high level of this emotion may suggest to the robot that it is unable to accomplish its goal, and it should try to get some help or to do something else. This can be done by deactivating the motive in question.
- *Anger*: monitors oscillations in the energy level, indicating difficult progress in the accomplishment of the goal associated with the motive.
- *Fear*: monitors constant energy level, indicating no progress in the accomplishment of the goal associated with the motive.

The influences from the analysis of the motive's energy level are also based on the amount of energy level and the priority of the motives. The priority of motives are attributed following the guidelines of Maslow's Hierarchy of Needs Theory (Maslow 1954). As the energy level of the active motive with the highest priority increases, its influences on the emotion variables increases too.

Theorically, we can illustrate the mechanism behind our model of artificial emotions with the following example involving *Energize*. As the voltage level of the batteries decreases, the energy level of *Energize* increases, causing an increase in the level of *Sadness*. When the energy level of *Energize* reaches 100%, *Fear* is also generated to indicate that the robot is now operating in dangerous conditions. *Fear* can be useful to help determine the robot with the highest need for recharging when more than one robot is waiting to recharge. As the robot starts to dock and has difficulties detecting the station, variations of the energy level generates *Anger*, which could help indicate to others to leave an area or to change the velocity of the robot to facilitate the detection of the charging station. And as the robot is recharging, the energy level of *Energize* decreases which influences *Joy*. If the robot leaves the station early, the amount of *Joy* would be less than if it leaves the station fully charged. This could indicate the amount of compromise the group must make to ensure the survival of the most individuals.

Figure 3: Group experiments having robots share one charging station.

Experimental Setup

The usefulness of artificial emotion is going to be revealed in complex adaptation problems, like the temporality adaptation problem of energetic autonomy of a group of robots. Our overall objective is to have the highest number of Pioneer 2 robots survive in an enclosed area by sharing one charging station while doing a foraging task. The experimental setup is shown in Figure 3. The idea is to make dynamic role selection in order to find the appropriate number of robots do the task and share the charging station over time and for the longest period possible, and at the same time optimize the accomplishment of the task and the survival of the whole group.

Having a group of robots share one charging station in an enclosed area is a rich experimental setup to study the usefulness of an emotional model. This challenging problem involves making a robot adapt to its limited knowledge on the remaining energy, on the time required to get access to a charging station, on the time required for recharging, and on the needs of others in the environment. It requires the integration of different capabilities for autonomous decision making based on internal and external considerations by the robot, and artificial emotions may just be the 'glue' required to make everything work. They can be beneficial to communicate the general state of each robot to the group, and regulate the social behavior in a distributed fashion.

Our strategy to validate the usefulness of artificial emotion in such context is to conduct a series of experiments starting with decision schemes without communication, with communication of relevant information about the group but without using emotion, and finally with communication and emotion. This way, we will be able to make comparison between the added mechanisms, their complexities and their impact on the performance of the group.

Conclusion

Such experiments on long-term adaptation in a social environment can serve as a good benchmark for distributed autonomous robotics systems (Yuta & Hada 1998). Performance criteria can be based on the amount of time the robots can survive and the accomplishment of the task by the group, studied in relation to the availability of the charging station and the amount of information communicated. The MICRobES Project (Picault 2000) is also interested in making robots recharge themselves autonomously and study their long-term adaptation in a social environment. However, no results involving physical robots have been presented yet. Earlier work done by Steels (Steels 1994; 1995) is the one closest to ours. It involves two robotic agents in an ecosystem in which competition for energy occurs. Light boxes placed in the environment are also draining energy available for recharging, and agents have to cooperate to make one agent recharge while the other is inhibiting the light sources. The approach is behavior-based and is also influenced by motivational processes. However, no communication (other than emitting a sound when an agent needs to recharge) is allowed between the agents. In comparison, energy is not the only element involved in the experiment: our robots must also accomplish a task concurrently. Egoism and altruism were addressed by Steels by setting up the experiment so that one agent cannot survive on its own. In our case, one agent could survive on its own, but this would affect the accomplishment of the task. Also, the robotic systems used by Steels are not capable to operate for days in a row, while with ours we are pursuing the goal of making as much mobile robots work for the longest period possible.

Currently, the charging station and the ability of the robots for autonomous docking are now working appropriately. As of now, we have made some tests with two robots, and the difficult part is to adjust the influence coming from the energy level of motives on the emotional variables. We are also elaborating social rules to be used by the *Rational* module that exploit emotional states communicated by the robot to make a robot using the charging station decide when to leave the charging station, to ensure that other robots can survive.

Acknowledgments

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