Abstract. The possible modulatory influence of motivations and emotions is fundamental in designing robotic adaptive systems. In this paper, we will try to connect the concept of periodic behavior activations to emotions, in order to link the variability of behaviors to the circumstances in which they are activated. We will study the impact of emotion, described as timed controlled structures, on simple reactive behaviors. We will show, through this approach, that the emergent behaviors of a simple robot designed with a parallel or hierarchical architecture are comparable. Finally, we will see that conflicts in behaviors may be solved without an explicit action selection mechanism.

1 Introduction

In Robotics one of the main issues in designing a control system is to enable an autonomous robot to react and adapt in useful time to environmental changes [1]. This reaction depends on the correct identification of objects and their properties by appropriate sensor devices, with a strong emphasis on the concept of the stimuli-response loop. Moreover, the robotic community, started to pay attention not only to the robot-environment interactions, but also, so to speak, to the interactions that may arise within the robots itself [2] and how these latter (for example its emotional states) may influence the emergent behavior of the robot.

In these last years some researchers [2–7] started to pay attention to the role of emotional and motivational states in order to achieve an adaptive emergent behavior of robotics systems. In particular, the role of emotions has been introduced for behavior modulations [3, 4], to provide adaptivity to environmental changes. Moreover, cognitive psychology considers thinking, learning and memory activities as a problem of information processing. However, the description of motivational issues and emotional states as a processing problem is not an obvious task [3]. The interest for such “internal mechanisms” comes within the robotic community taking inspiration from ethological, biological and neuroscience studies. In our opinion, in order to model different and new architectures for controlling the robot behavior, both these aspects (the interaction with the surrounding world and the internal states) have to be considered, since they influence each other. For example, the simple perception-action response to an
external stimulus may produce different patterns of actions consequently to a
different internal state of the robot. This internal state may change according to
his emotional or motivational state or following its past perceptions and it will
tune and adapt both the executions of different behaviors for the robot and the
processing frequency of the sensors’ inputs. Our working hypothesis is that such
adaptive behaviors can be achieved in the control activity of a robot starting
from self-regulated periodic mechanisms.

In previous papers [8, 9] we highlighted the opportunity of managing the
frequency of processing the sensors inputs in an efficient way, because it may
have negative effects on the robot behavior. This kind of problems leads us to
find a solution for the efficient use of the Robotic sensor apparatus. Therefore,
we moved to study how rhythmic computations may be introduced in a con-
trol mechanism for robotics systems and how such introduction may lead to a
framework that will cope with some of the common problems in designing con-
trol systems for robots. In this paper we will analyze our architecture in terms
of emergent behavior driven by motivational and emotional states, and we will
describe how our architecture may deal with conflicting behaviors (for example,
predator avoidance and food acquisition) starting from the concepts of period-
ical adaptive activations of behaviors. We present a robotic architecture that
has the capability of adapting its behavior to the rate of change of a dynamic
environment - e.g. of tuning the velocity of reaction to the external stimuli co-
herently to the changes occurring in the environment. On the other hand, we
want our model to take into account that such stimuli may come not only from
the external environment (as a bottom-up process), but they can be generated
by the robot itself (top-down) [2] - e.g. the robot has to adapt its perceptual
system according to its “needs”.

2 AIRMds

A motivation-based architecture should be able to integrate a combination of
internal and external factors to select the appropriate behavior. However, these
architectures are not always sufficiently adaptive to unpredictable environmen-
tal changes [4]. What we want to achieve is the ability, for a robotic system,
of adapting its emergent behavior to the surrounding environment and to its
internal state. At the same time we want the robot to opportuneely react accord-
ing to environmental changes and to efficiently spend the resources necessary to
monitor the surrounding environment. To achieve this goal we started from the
consideration that a wide type of behaviors are generated by the so called central
pattern generators [10], i.e., central oscillators whose output modulates rhythmic
movements. The role of such oscillator in coordination of motor patterns [11],
such as breathing and walking, is well accepted in neuroscience [12].

So, we would like to have a control system for the percept inputs that per-
forms a quasi-periodic activity (i.e. it has at least an active and inactive phase)
and should be flexible (i.e. dynamically adapt its period and amplitude to exter-
nal and internal constraints). In particular we would like to associate a periodic
control system to the activation of each single behavior. Lorentz [13] and Tinbergen [14] identified in many animals an innate releasing or inhibiting mechanism (IRM) able to control and coordinate behaviors. An IRM presupposes a specific stimulus that releases a pattern of actions. For example, a prey animal may have, as an IRM, the stimulus coming from the view of the predator, which activates the escape behavior. IRMs were included in the schema representation of behaviors [15] in the form of releasers, controlling when behaviors must be activated or deactivated. A releaser may be an activation mechanism that depends both by exogenous factors, that trigger an emotional state (a particular environmental condition – for example a prey that detects the presence of the predator), and by endogenous factors (a motivational state – for example hunger).

Fig. 1. A schema representation [15] of releasers and biological clocks. The function $\sigma_r(t)$ represents the input coming from sensors at each time interval; $\pi(t)$ is the command sent to actuators; $\sigma(t)$ represents the inputs elaborated by the perceptual schema and sampled by the function $\rho(t)$.

The releaser’s function, somehow, recalls the notion of “internal clock”, already introduced in some approaches [7, 16] in order to activate motivational states for a robot (for example, hunger or sleep). In fact, an internal clock, as a releaser, is a mechanism which regulates the behavior of living organisms. Moreover, this may depend on endogenous factors (i.e., independent from external environment) or exogenous factors. Starting from this analogy, we try, in some sense, to abstract the concept of internal clocks and to connect it to periodic activations of behaviors in a robotic architecture, in a similar way as a mechanism for releasing is related to a behavior using any representative models well studied and used in the Robotic community [15]. There are, however, substantial differences between the two concepts. An internal clock is responsible for the activation of a particular behavior, but has something more than a releaser (see Fig. 1). First of all, the releaser acts as a control signal for the whole behavior and it, somehow, may involve an elaboration of the input (for example a releaser may be the presence of a predator). An AIRM (Adaptive Innate Releasing Mechanism), instead, works only on the perceptual schema and has an active (or inactive) state that depends also on endogenous factors (the perceptual schema elaborates the input when the AIRM is active). Furthermore, internal clock may imply a regular and periodic activation of the perceptual schema of a behavior, whose activations in time may be predicted – and so, also the amount of resources spent for the elaboration of inputs. Instead, the activity of a releaser depends only on contingent factors. In [8, 9] we connected the concept of IRM
to the concept of a periodical activation of behaviors (AIRM). In this way, no computational resources are spent to elaborate not needed stimuli, because the corresponding control systems are kept “inactive” until a new periodical activation takes place, and at the same time we are able to control the amount of resources spent in the elaboration of the sensors’ inputs. Moreover, the introduction of internal clocks, within a robotic architecture, has also the effect of controlling behaviors that may require a fixed pattern of activation in time. This activation of behavior may be interpreted as large time scale activities, for example the activation of macro-behavior like feeding or sleeping, or as short time scale activities, in the sense of central-pattern generators in controlling rhythmic movements of a robot as walking, but also as a general mechanism for controlling activation of simple behaviors. Finally, we foresee that the introduction of such asynchronism in the robot control system may lead to an emergent behavior that is able to change and adapt according to its context without having an explicit action selection mechanism.

We assume the hypothesis of an architecture with some periodic releasing mechanisms of activation of behaviors. Such mechanisms, according to the environment, speed up or gradually slow down the period of behaviors activation and thereby the reading frequency of the sensors. In this system, however, the feedback does not come only from the outside, but can also be generated by the robot itself [2], allowing the robot to adapt itself also according to its emotional or motivational state. An emotional state, in our work, has to be interpreted, following the Damasio definition [17], as an unconscious and automatic response in reaction to a stimulus that involves an adjustment in homeostatic balance as well as the enhancement of specific behaviors. Moreover, in neuroscience, while classical theories of sensory processing view the brain as a passive, stimulus-driven device, more recent approaches [18] view the perception as an active and highly selective process.

Our working hypothesis is that each behavior of a Robotic System (RS) may be provided with clocks that control the periodic activation of behaviors. We may think that each of the releasers, that manage the various micro/macro-behaviors, is activated by an individual clock with a variable period $p_\beta$, as it will be explained in the following, depending on the purpose of the behavior and on the sensors data involved in the behavior. Timed releasing functions take data from a perceptual schema and from the internal state of the robot and return enabling/disabling signals to the perceptual schema itself. That is, the perceptual schema of a behavior is regulated by an internal clock that says how frequently the inputs have to be elaborated. For example, if the initial value of the period of a clock is of four time units, it means that the input from the sensors for this particular behavior will be processed only every four time units. In the other cases, during the inactivity state of the perceptual schema, no new commands will be send to the motor schema and so no new actions will be produced.

In our architecture, motivational behaviors have an impact on the value of the period of each behavior and so they can regulate and modify the perceptual abilities of the robot as well as its actions in time. Motivational and emotional
behaviors may be induced both by internal states of the robot (for example, hunger), coded as linear time-dependent functions, and as an emergent process from the interaction with the environment (for example, fear).

3 Implementation and Testing

Let us assume that each behavior of the robotic system has a variable period initially equal to a preferred value. In our experiments, we assumed that these periods are proportional to powers of two. We designed a system whose behavior is mainly guided by the visual information in a 3D environment. In particular, according to [5], the reaction of the robot may be driven by moving objects. In order to achieve the proper reaction of the robot in respect to a moving object, we implemented a control schema to change the period of the clock based on the Weber law of perception. We already discussed in section 2 the perceptual schema modulation according to a periodic releasing function. In particular we noticed that the robot can evaluate the perceptual inputs only when the releaser/clock is on. While the reaction of the robot depends on the perceptual inputs (for example, the robot that sees a predator will produce an action to escape) the self-regulation mechanism, encoded in the internal clock, will confront the current percept with the last available percept, stored in the temporal or working memory of the robot. The change in its emotional state (encoded as a change in the releasing period) depends on how much this value has fluctuated. However, in order to set the appropriate thresholds for evaluating this change, we cannot refer to absolute values. In this sense the Weber law allows us to compute the relative change in the percept input ($\sigma(t)$) as $\frac{\Delta \sigma}{\sigma}$. In figure 2 the percept input of an experiment is plotted. The dotted lines represent the thresholds we use to adapt the period of the releasing function according to the values of the input percept. In fact, in order to make the robot able to react in time, for an increasing percept we want the period to decrease according to the input changing rate. Let us remark that, in our approach, the period of a behavior may change its value, varying among power of two values. Moreover, also the selected thresholds for changing the period are proportional to a power law. For example, if the percept exceeds the first threshold, the period will be halved; instead, if the percept exceeds the second threshold, the current value of the period will be reduced to a quarter, and so on. On the contrary, when we have a decreasing function, we want the process for coming back to the maximum value of the period to be slow.

In order to test our working hypotheses we used a PIONEER 3DX provided with a blob camera (see Fig.3). The robot architecture is constituted by four simple behaviors: WANDER, FIND FOOD, EAT and ESCAPE. In particular we were interested in observing only the FIND FOOD and ESCAPE, whose perceptual schemas were controlled by AIRMs and whose behaviors may be in conflict requiring an action selection mechanism. We implemented both a subsumption architecture (see figure 4(a)) with ESCAPE subsuming FIND FOOD and a parallel architecture (see figure 4(b)) whose output was the sum of the outputs of the two behav-
iors. The output ($\pi_i$) of these two behaviors consists in a predefined velocity and direction, except for the ESCAPE behavior whose output velocity depends on the internal clock. In particular, if the value of the clock is equal to the initial maximum value, the module of the velocity will be equal to the velocity set by FIND_FOOD. If this value is equal to the minimum value, the velocity will be set to a much higher value in order to escape. In all the other cases, velocity will be a constant value in between the maximum and the minimum values.

Let us suppose that a red object represents a predator and a green object represents food (see Fig.3(a)). What if the system is in the case of having in the same direction both the food and the predator (see Fig.3(b))? In this situation the emergent behavior will depend on motivational states and will be influenced by their impact on the activations of behaviors. The FIND_FOOD behavior has an internal clock with a period whose value depends on the motivational state of “hunger”. This state is regulated by a linear time-dependent function, and this means that at the beginning, when the value of the hunger is low, the FIND_FOOD behavior is released with a predefined period that depends on the life cycle of the robot. During the simulation, the hunger value will grow in time and, accordingly, also the period of the clock of the corresponding behavior will be reduced. When the behavior is enabled and the robot senses a green object, the output of the FIND_FOOD behavior will set the direction of movements towards the food. The ESCAPE has an internal clock that simulates the state of “fear”. At
the beginning of the simulation the value of the period is set in order to safely check the presence of a predator. If the robot senses a red object (the predator) and the behavior is enabled, the output of the behavior will be a movement in the opposite direction of the predator. The period of this clock does not depend on an internal variable (like in the case of FIND_FOOD), but on the changing of the value of the percept itself according to the Weber law. This means that the “fear” of the robot will increase if the predator is moving toward the prey (i.e., the period will be reduced). Moreover, let us highlight that this process will have, as a consequence, an adaptation of the behavior of the robot if the predator is not moving. However, in the case of both the food and the predator in face of the robot, while approaching the food the movement of the robot itself may induce a change in the perception of the dimension of the red blob.

Fig. 4. Subsumption (a) and parallel (b) implementations of behaviors. For each case the plots show the changing of the input (red area), of the two clocks (fear and hunger) and of the position of the robot towards the food at each time unit.

In figure 4 we plotted some results for the case study described above. The first plot refers to the subsumption implementation of the behaviors, while the second one refers to a parallel architecture. The first plot of each of the two cases represents the percept (i.e., red blob area for the ESCAPE behavior). Such
percept is sampled according to the corresponding internal clock that simulates fear. Let us notice that while the internal clock is inactive the robot does not update its perceptual input, which remains constant until the next activation of the clock. Moreover, let us notice how the frequency of activations of the clock is modified following the input percept. The last part of each plot represents the internal clock of the FIND FOOD behavior, that depends on time. As soon as this value increases more than the value of the ESCAPE behavior, the robot will start to move toward the food with an oscillating behavior that will lead to reach the position of the food. Let us notice that the emergent behavior of both the two approaches, represented by the changing of the position of the robot towards the food, is comparable, in the sense that both the approaches, if the behaviors are controlled by internal clocks, will lead to the same oscillating pattern towards the food. The only substantial difference between the two approaches happens when the hunger is low: in fact, while in the subsumption architecture the robot will move in the opposite direction of the food (and the predator), in the parallel architecture the robot is not moving.

![Fig. 5. The robot emergent behavior with different initial values of the ESCAPE clock.](image)

In figure 5 we compared the emergent behavior of the same robot with a parallel architecture, changing the initial maximum value for the period of the ESCAPE behavior. First of all, let us highlight that the emergent behaviors of the robot seem not to depend on this initial value. The explanation of this situation, in this particular case study, is that while approaching the food the clock of the ESCAPE behavior frequently changes its value, also for the presence of the predator. This oscillation pattern makes the robot not able to return the initial value of the ESCAPE period that keeps oscillating between the minimum value and a constant average value. However, while in this case it seems that the maximum value of the ESCAPE period does not have any impact on the emergent behavior, we want our robot to react in useful time to moving obstacles (i.e., the predator). In Fig.6 we plotted the changing of the red area and, accordingly, the changing of the period of the clock of the ESCAPE behavior and the changing in the velocity of the robot in the case that the red object starts to move (see
Fig. 3(c)). Let us notice that when the period reaches its minimum value the module of the velocity is bigger in order to escape.

Fig. 6. Robot reaction to a moving obstacle.

4 Discussion

In this paper, we started to explore the feasibility of designing robotic architectures based on motivational modulation of behavior activities by means of periodic releasers. The embedding of such controlled rhythms within a RS behavior allows the realization of flexible/adaptive behavior which can realize timed activation of the behavior itself as well as modulation of its performance according to its internal state and sensorial information. Other authors dealt with this kind of problems. For example, in [7] the authors presented a parallel architecture focused on the concept of activity level of each schema which determines the priority of its thread of execution. A more active perceptual schema can process the visual input more quickly and a more active motor schema can send more commands to the motor controller. However, while in our approach such effects are obtained through rhythmic activation of behaviors, in [7] the variables are elaborated through a fuzzy based command fusion mechanism.

Moreover, behavior based robotic usually resolves conflicts by using a subsumption architecture or by implementing some control mechanisms in order to switch between tasks, selecting the action. For example, in [5] the authors presented a schema theoretic model for a praying mantis which behaviors are driven by motivational variables such as fear, hunger and sex-drive. In this approach, the action selection module takes into account only the motivational variable with the high value. As in our case, when the hunger is too high the robot will move toward the food even through there is a predator in sight. Moreover, fear depends of the view of the predator, but when the predator is in the field of view of the prey this variable is only set to a predefined high value.

Let notice that while a motivational behavior may have a linear model of development, emotions are not a linear succession of events [6]. In our approach we presented a model of an emotional behavior that does not depend only on linear time dependent functions, but it is directly connected to the changing
rate of the surrounding environment. However, while for a simple case study
our architecture was able, by means of asynchronous computation, to act like
an action selection mechanism and to adapt to its context, one of the problems
of more complex parallels architectures comes from the possibility of arising
interferences between different processes. Since emotions and motivation are not
independent processes, as future work we will move forward in the direction of
studying how these adaptive periodical activations of behaviors may influence
and constrain each other.

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