An Autonomous Robot that Learns Approach-Avoidance Behaviors: Lessons from the Brain to the Robot

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1 Introduction

The main thrust of this research project is the search for principles of organization inspired in biological systems for the design of autonomous artificial systems. Despite all the scientific/engineering effort in the last decades, biological systems remain orders of magnitude more *robust*, *adaptive* and *flexible* than artificial systems [3]. In this paper we introduce an autonomous robot BARTOLO (Behaviorally Adaptive Robot That Learns Objectives) that incorporates several of these principles of organization.

BARTOLO incorporates a visual system capable of robust object segmentation and recognition based on very adaptive neural principles. More specifically it includes synchronization in cortical structures to segment different objects in the visual field and unsupervised learning of internal representations that allow to discriminate between the different objects. The output from the perceptual system undergoes a sensorimotor transformation to map from retinotopic coordinates to motor coordinates. All the parameters required for the transformation are learned by the robot while interacting with the environment. The selection of motor actions is also a very adaptive process including a reinforcement learning component.

Summarizing, many of the central concerns in the design of *autonomous agents* have been addressed in this research project, namely: sensing and perception, action selection, learning in autonomous robots, and so on. We close the loop by evaluating the robot against a quite complex environment to show that many of these principles, even in primitive form, give rise to complex emergent behavior.

Next we shall describe the main componentes and principles of organization that underly the design of BARTOLO. Due to space constraints we can only present in schematic form several of the components that constitute the whole system. The environment BARTOLO inhabits is a typical research laboratory, where we have situated some boxes as obstacles. Some of the boxes in the room have symbols painted on them such as crosses, bars at different orientations, and so on.

2 Components

The **visual system** of BARTOLO is composed of three main elements: a preprocessing of the camera image and two neural networks which achieve robust and flexible segmentation and recognition through biologically plausible mechanisms.

[8] describe in detail each of the components following all the steps the image goes through since it is captured by the camera until a decision is taken.

The **sensorimotor system** must transform object coordinates in retinotopic space to command parameters in motor space. Two coordinates need to be computed in order to complete the task in hand, namely, orientation angles and approach/avoidance distances. Next we will describe in some detail how both are computed as well as the learning mechanisms to tune the corresponding parameters in charge of the computations.

The **motor system** incorporates the following motor primitives (i.e. motor schemas): forward f, backward b, and orient α where f, b, α are the parameters for the respective motor primitives. These motor primitives are then composed to yield more complex behaviors (e.g. aproach, avoid).

In general a pattern of activity in the same retinotopic coordinates may come to represent very different things. Hence, the robot must decide on a course of action based on the integration of information currently available in its sensory system as well as on information learned during its previous interactions within the environment (discussed in next section). The specific parameters f, b, and α are computed by the sensori-motor transformation processes.

One of the central features in the design of any robust autonomous system is that learning must be integrated all over the components of the system ([3],[4]). As we have already described, most of the structures in the robot's brain are adaptive, including the following: self-calibration for orientation; unsupervised learning of internal representations for object recognition. We have also included reinforcement learning to associate approach/avoidance behaviors to the different objects in the environment. We want BARTOLO to approach objects labelled with crosses and avoid objects labelled with vertical bars, the others being neutral.

3 Results: Emerging Behaviors

Next we describe the behaviors that emerge when BARTOLO is left to interact with the laboratory environment where it inhabits.

- Obstacle Avoidance (B1): BARTOLO learns to avoid colliding with the different obstacles (including the walls). No ultra-sound sensor is used but the avoidance behavior is triggered based only on the visual input. To facilitate the task of segmentation the floor has a distinct color than the walls.
  Behavior Evolution: Initially the robot approaches any object different from the floor (including the walls) in a reactive manner. We follow a conservative approach in that initially it does not get too close to the target object and then it is tuned to approach closer and closer while avoiding colliding.
- Dynamic Goal Approach and Avoidance (B2): BARTOLO learns to orient, approach and touch a subset of the objects in the environment as well as avoid others. For the rest of the objects BARTOLO learns not to trigger

any specific response (the exploratory behavior takes control). This behavior results of: learning to recognize/discriminate objects, learning to orient towards objects in its RF, learning to approach and learning the inherent "semantics" of entities by reinforcement (learning). Behavior Evolution: Initially the robot is not able to discriminate between the different entities in its environment so it approaches all of them. Eventually it learns to discriminate which ones provide positive reinforcement and which ones provide negative reinforcement.

4 General Principles of Organization

- Self-organization: the autonomous robot is left to interact with the environment and, in the process, constructs its own internal representations of the external entities rather than have them prewired by the system's designer.
- Synchronization for feature binding: Features belonging to the same external entity should be bound together and segmented from those of other entities.
- Parcellation: The different components of target location (eccentricity, elevation and depth) are handled through different channels that can be disturbed independently (Grobstein, 1988).
- Self-regulation: Autonomous activity is self-regulated to obtain robustness under varying conditions (cf. continuous learning, developmental learning).
- Dynamic goal generation: goals should be dynamically constructed by the system during its interaction with the environment (cf. internal drives and motivations).

5 Conclusion

This paper presents a set of principles of organization to design autonomous robots inspired in those of their biological "siblings". As a proof of concept we have constructed BARTOLO, an autonomous robot that learns approach/avoidance behaviors. Thanks to the features of the biological principles of organization the robot inherits the following features: *flexibility*, *robustnes* and *adaptability*. Future and work on progress includes: path following behavior signaled by arrows, complex delayed reinforcement, predictive learning for distal learning, and so on.

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