From continuous analog to discrete symbolic representations of the world in optimal foraging: a robot based study

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HIGH-LEVEL SYMBOLIC REPRESENTATIONS

A fundamental question in our study of advanced cognitive functions is how high-level symbolic representations can be generated on the basis of continuous and analog sensor states. In this study we approach this problem from the perspective of the biomimetic Distributed Adaptive Control architecture (DAC) [1]. DAC is a multi-layer architecture that provides mechanisms for reactive actions, adaptive and contextual control. Here, we address the question of how optimal allocentric symbol based goal oriented behavior, as supported through the memory systems of the contextual layer, can be acquired and expressed on the basis of the egocentric interactions with the environment that are supported by the reactive layer. In particular we focus on the adaptive construction of discrete symbolic representations in the service of goal-oriented behavior. In order to address this question we extend the reactive layer with a biologically constrained model of allostatic control that allows the flexible regulation of behavioral modes.

ARCHITECTURE AND ENVIRONMENT

DAC architecture [1] is based on the assumption that "initially" the behavior is guided by reactive responses that drive the agent to specific goal states, e. g. reach "food" or "home", depending on the robot's internal motivation, i. e. its own reward and security states. This interaction with the environment allows acquisition of a state space that describes the task domain combined with the shaping of actions, i.e. acquisition and retention of salient information of past experiences. This information learned is used on future occasions to drive robot's behavior based on its internal motivation. In this study, we extend the reactive layer of DAC with an allostatic control (Figure 1) which allows the robot to explore the environment guided by innate responses as a result of drive based gradients that are projected into the environment.

AR-CHI-TEC-TURE

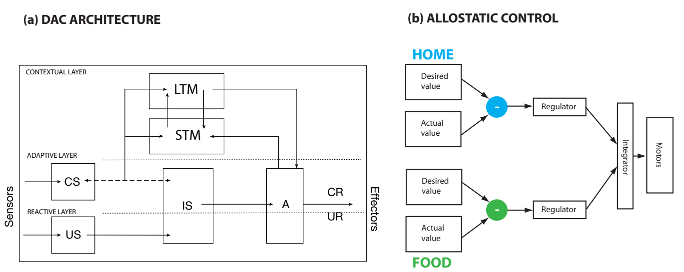
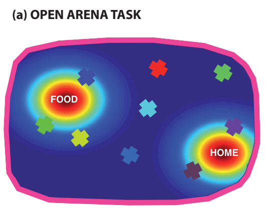


Figure 1. (a) DAC is based on the assumption that behavior results from three tightly coupled layers of control: reactive, adaptive and contextual. Squared boxes stand for neuronal groups. Arrows stand for static (solid line) and adaptive (dashed line) synaptic connections between cell groups. Abbreviation: US, unconditioned stimulus; CS, conditioned stimulus; IS, internal states; A, action group; UR, unconditioned response; CR, conditioned response; STM, short-term memory; LTM, long-term memory. **(b)** In the allostatic control the actions of the robot are controlled based on the internal states of the robot (desired value) and the current state of the environment (actual value assessed through the sensors). Each allostatic subsystem (home, food) is controlled by a separated homeostatic regulator. The outputs of the subsystems are integrated and an action is selected by priority.

To test our model we define an environment with two goal states placed into it: "home" and "food" (see Figure 2a). The robot has an internal security state which has a high value when its position is near "home" and a low value when it is far away from "home", i.e. when looking for food. The robot explores the environment based on its internal motivation.



ENVI-RON-MENT

Figure 2. (a) The environment has two goal states: "food" and "home". The allostatic control system is based on the ascend of gradients that are projected into the environment. The role of the behavioral subsystems in the generation of actions of the robot is guided by the internal drive states, e. g. "hunger" and "security" with "home" and "food" as the goal states that the robot might want to reach. The gradients follow a Gaussian distribution centered on the positions of the home base and food in the environment. **(b)** The robot is a Khepera robot simulation. It is implemented in C++ and wSim [2] using the Open Graphics Library.

ROBOT NAVIGATION

EXPERIMENT 1: "Food" and "Home" gradients are projected into the environment. Since the robot's internal security state changes to low values when it is far from home the robot comes back home to feel secure. Therefore, the robot spends most of the time near home satisfying its internal motivation (Figure 3).

DAC architecture constructs symbolic information from a continuous interaction with the world. Sequences of patches/actions and goal state are stored in memory. Figure 4a shows a sequence of patches (wall - red - purple) stored in one position of the memory. Figure 4b shows the actions that were performed during the sequence in Figure 4a. Therefore, when a wall was seen a left action was performed and a right when red and purple patches were presented.

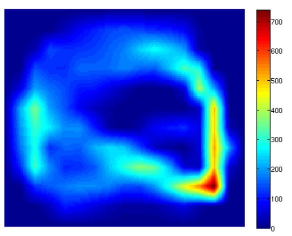


Figure 3. Density plot of the trajectories of the robot.

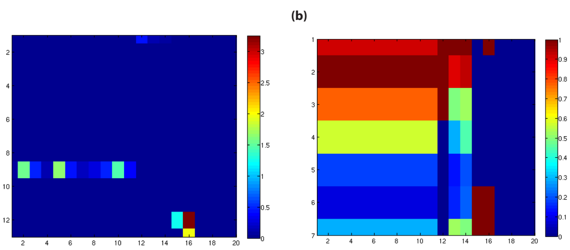


Figure 4. Symbolic representations. **(a)** Patches representations. **(b)** Actions representations.

EXPERIMENT 2: The gradients are off and the reactive and contextual performance are tested. When the gradients are not present innate responses fail to lead to goal positions (home). They are only reached by chance. The contextual layer performance is higher than the reactive layer performance (Wilcoxon rank sum test $p < 0.05$), being able to correctly recall previous gathered information (see Figure 5).

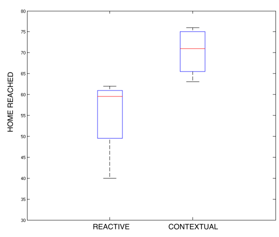


Figure 5. Reactive and contextual layers performance.

CONCLUSIONS

The new contextual control system of DAC allows the robot to recall different weighted information from memory based on its internal states and generate optimal solutions to realistic foraging problems. Moreover, to have the DAC architecture on top of the allostatic control implies a change in the world representation: from its continuous analog representation to a discrete symbolic representation. This results in an optimal behavior even when the gradients are not projected into the environment. As a further step, we plan to validate the model on a real-robot with multiple goal states and multiple changing internal motivations.

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