Introducing Sensory-motor Apparatus in Neuropsychological Modelization

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Abstract. Mainstream modeling of neuropsychological phenomena has mainly been focused to reproduce their neural substrate whereas sensory-motor contingencies have attracted less attention. In this study we trained artificial embodied neural agents equipped with a pan/tilt camera, provided with different neural and motor capabilities, to solve a well known neuropsychological test: the cancellation task. Results showed that embodied agents provided with additional motor capabilities (a zooming motor) outperformed simple pan/tilt agents, even those equipped with more complex neural controllers. We concluded that the sole neural computational power cannot explain the (artificial) cognition which emerged throughout the adaptive process.

Keywords: Neural agents, Active Vision, Sensory motor integration, Cancellation task

1 Introduction

Mainstream models of neuropsychological phenomena are mainly based on artificial bioinspired neural networks that explain the neural dynamics underlying some neurocognitive functions (see for example [4]). Much less attention has been paid to modeling the structures that allow individuals to interact with their environment, such as the sensory-motor apparatus (see [5] for an exception). The neurally-based approach is based on the assumption that the neural computational power and its organization is the main source of the *mental life*. Alternatively, as stated by eminent theorists [8, 9, 11], cognition could be viewed as a process that emerges from the interplay between environmental requests and organisms' resources (i.e. neural computational power, sensory-motor apparatus, body features, etc.). In other words, cognition comes from the adaptive history (phylogenetic and/or ontogenetic) in which all living organisms are immersed and take part. This theoretical perspective leads to building up artificial models that take into account, in embryonic form, neural structures, sensory-motor apparatus, environment structure and adaptation processes (phylogenetic and/or ontogenetic). This modelization approach is developed by the interdisciplinary field of Artifcial Life and it is widely used in order to modelize a large spectrum of natural phenomena[3, 10, 6, 7]. In this study we applied artificial life techniques to building up neural-agents able to perform a well known neuropyschological task, the cancellation task, currently used to study the neurocognitive functions related to spatial cognition. Basically, this task is a form of visual search and it is considered as a benchmark to detect spatially-based cognitive deficits such as visual neglect [1].

2 Materials and Methods

2.1 The cancellation task

The cancellation task is a well known diagnostic test used to detect neuropsychological deficits in human beings. The test material typically consists of a rectangular white sheet which contains randomly scattered visual stimuli. Stimuli may be of two (or more) categories (for example triangles and squares, lines and dots, *A* and *C* letters, etc.). Figure 1a shows an example of the task. Subjects are asked to find and cancel by a pen stroke all the items of a given category (e.g. *open circles*). Fundamentally, it is a visual search task where some items are coded as distractors and other represent targets (the items to cancel). Brain-damaged patients can fail to cancel targets in a sector of space, typically the left half of the sheet after a lesion in the right hemisphere (visual neglect, see figure 1b).Here we simulated this task through a virtual sheet (a bitmap) in which a set of targets and distractors are randomly drawn (Fig. 1c), and trained neural agents provided with a specific sensory-motor apparatus, described in the next section, to perform the task.

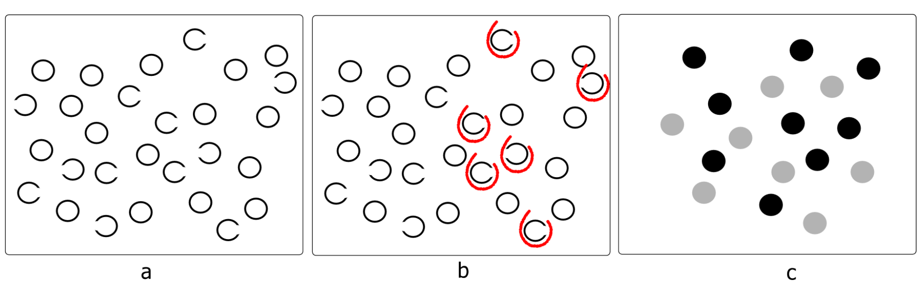

Fig. 1. a) Cancellation task in which targets are open circles and full circles are distractors; b) open circles canceled with a circular mark; c) cancellation task implemented in our experiments: grey filled circles are targets and black ones distractors

2.2 The neural agent's sensory-motor apparatus

A neural agent is equipped with a pan/tilt camera provided with a motorized zoom and an actuator able to trigger the cancellation behavior (Fig.2). The camera has a resolution of 350x350 pixels. Two motors allow the camera to explore the visual scene by controlling rotation around x and y axes while a third motor controls the magnification of the observed scene. Finally, the fourth actuator triggers a cancellation movement that reproduces in a simplified fashion the behavior shown by human individuals when asked to solve the task. The

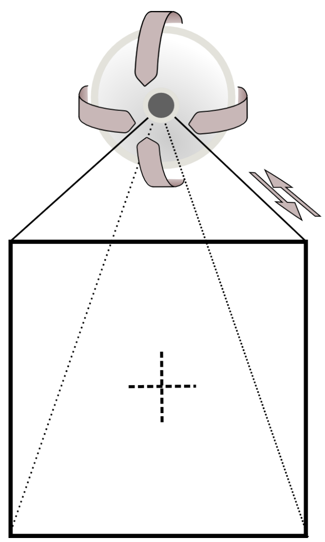

Fig. 2. The sensory-motor apparatus: two motors control rotation around two axes, one motor controls the zoom and a supplementary motor (not depicted) triggers the cancellation behaviour.

behavior of the neural agents is controlled by a neural network able to control the four actuators and to manage the camera visual input. The camera output does not gather all the pixel data, but pre-processes visual information using an artificial retina made up of 49 receptors (Fig. 3, right). Visual receptors are equally distributed on the surface of the camera; each receptor has a round visual field with a radius of 25 pixel. The activation of each receptor is computed by averaging the luminance value of the perceived scene (Fig. 3, left)

2.3 The cancellation task on the artificial neural agent

In order to simulate a form of cancellation task in silico, we trained neural agents endowed with different neural architectures to perform the cancellation task. In particular, we presented a set of randomly scattered stimuli made up of

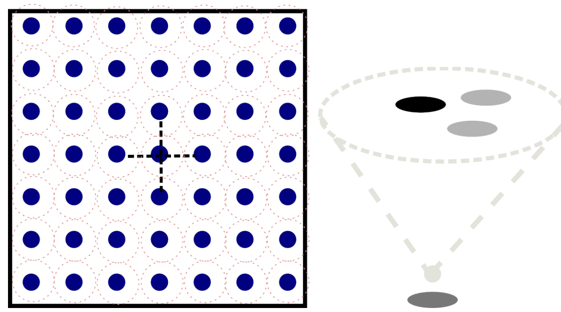

Fig. 3. Right. Neural agent's retina. Receptors are depicted as blue filled circle, receptive fields as dotted red circles. Left. Receptor activation is computed averaging the luminance value of the perceived stimuli.

distractors (black stimuli) and targets (grey stimuli) (Fig. 4) and rewarded neural agents for the ability to find (by putting the center of their retina over a target stimulus) and cancel/mark correct stimuli (activating the proper actuator).

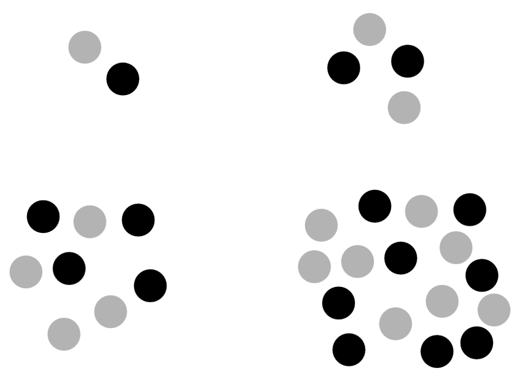

Fig. 4. Random patterns of targets (gray filled circles) and distractors (black filled circles)

2.4 Experiments

In order to perform the cancellation task, an agent has to develop (1) the ability to search for stimuli, and (2) to decide whether a stimulus is a target or not. To study how these abilities emerge we used controllers which were able to learn and self-adapt to perform the task. We provided agents with neural networks with different architectures designed by varying the number of internal neurons, the pattern of connections and the motor capabilities. In particular, we designed four architectures of increasing complexity (Fig. 5). Complexity was determined first by the number of neurons and by their connections. In this case more complexity turns on more computational power that a controller can manage. Second, complexity can be related to the body in terms of sensory or motor resources that can be exploited to solve a particular task.

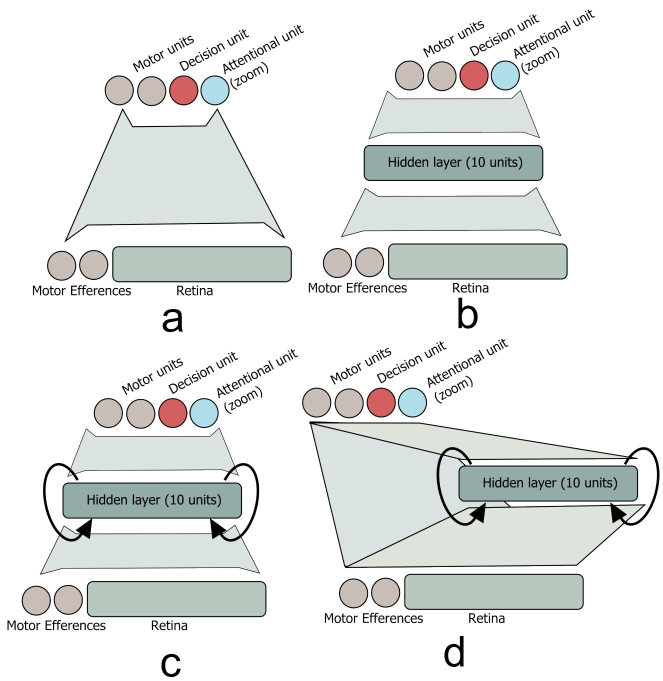

Fig. 5. Networks trained for the cancellation task: a) Perceptron; b)Feed forward neural networks with a 10 neurons hidden layer; c) Network b with a recurrent connection; d) Network c with a direct input-output connection layer.

In 8 evolutionary experiments, we trained neural agents by varying the controllers' architecture (4 conditions) and by adding the possibility to use or not the zooming actuator (2 conditions). For each experiment 10 populations of artificial agents were trained through a standard genetic algorithm [8] for 1000 generations. For each generation neural agents were tested 20 times with random patterns of target and distractor stimuli. Each agent was rewarded for its ability to explore the visual scene and correctly cancel/mark target stimuli.

3 Results

For each evolutionary experiment we post-evaluated the best ten individuals for the ability to correctly mark target stimuli. In particular, we tested each individual with 800 different random stimuli patterns.The rationale behind the post evaluation is twofold. First, during evolution each agent experienced a small number of possible visual patterns (20); second, the reward function was made up of two parts so as to avoid bootstrapping problems: one component to reward exploration and the second one to reward correct cancellations. Results are reported as proportion correct in cancellation tests. Figure 6 reports the post-evaluation results for each architecture in each motor condition: with the ability to operate the zoom (Fig. 6 a,b,c and d) and without this ability (a-, b-, c- and d-).

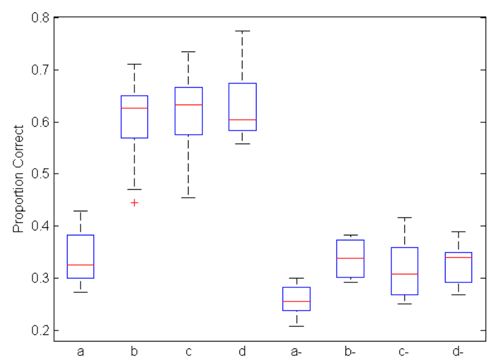

Fig. 6. Boxplots containing the post evaluation performance for each evolutionary experiment. Each boxplot reports the performance of the best 10 individuals.

For all the neural networks we found significant differences ($p<0.001$, two-tailed Mann-Whitney U test) between the condition presence/absence of the capacity to zoom incoming stimuli. In both groups there were significant differences between network a and the remaining networks, but no significant difference emerged between networks b, c and d. Interestingly, there were no significant differences between a, $b-$, $c-$, and $d-$. This last result suggests that a greater computational power can replace to some extent the absence of a zooming capacity. As mentioned above, neglect patients fail to process information coming from the left side of space. However healthy individuals can also show mild signs of spatial bias in the opposite direction (i.e., penalizing the right side of space), a phenomenon termed pseudoneglect [12]. In order to asses if such bias could simply have emerged as a side effect of the training process, we tested the best evolved individuals of the network d with a set of 200 couples of target stimuli placed symmetrically respect to the x axes of the artificial agent. Results (Fig. 7) show that only one individual (nr. 3 in Fig. 7) did not present a significant left-right difference, while all the remaining had different degrees of spatial preference.

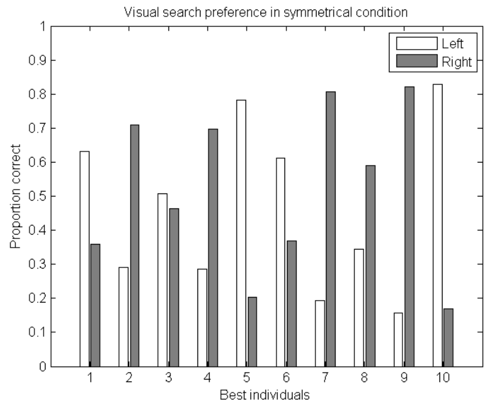

Fig. 7. Individual proportion correct in the selection of left or right-sided targets as first visited item.

4 Conclusion

At variance with the mainstream approach in the modeling of neuropsychological phenomena, mainly focused on reproduction of the neural underpinnings of cognitive mechanisms, we showed that having a proper motor actuator can greatly improve the performance of evolved neural agents in a cancellation task. In particular, we demonstrated that an appropriate motor actuator (able to implement a sort of attentional/zooming mechanism) can overcome the limits associated with intrinsic computational power (e.g. number of internal neurons and neural connections in our case). Second, we showed that spatial bias in stimulus selection in *healthy neural agents* can be a side effect of the training process. In future extensions of this work we plan to test *injured neural agents*, evaluate biologically-inspired neural architectures following recent research results on brain attentional networks[2] and to extend the range of different explored sensory-motor capabilities.

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