

## Place cognition as an example of situated cognition: a study with evolved agents

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### Introduction

The discovery of ‘place cells’ in the hippocampus of the rat was a seminal finding in the cognitive neuroscience of space processing (O’Keefe and Dostrovsky 1971). Place cells are pyramidal neurons in CA1 field of the dorsal hippocampus whose firing strongly depends on the rat’s location in a given environment. The discharge pattern of these cells is associated to a well-defined area of the environment where the unit maximally fires, the so-called ‘place field’. In O’Keefe’s words, a place cell is “a cell which constructs the notion of a place in an environment by connecting together several multi-sensory inputs each of which can be perceived when the animal is in a particular place in the environment” (1979, p. 425). Complementary to the information about position is the information about direction, provided by head direction cells, neurons that fire only when animals have their head in a certain direction. Recently, a new class of cells has been discovered whose firing depends on animal’s position. These are the grid cells (Fyhn et al. 2004) in dorsocaudal medial entorhinal cortex (dMEC), which are activated when the animal occupies

a vertex of a regular grid that spans the entire surface of the environment.

These findings support the hypothesis that in various areas of mammals’ brain there are topographic neural maps that converge to spatial representation: in the hippocampus whose basic unit is the place cell and in the dMEC whose basic unit is the grid cell. Both these cells share a property: their firing defines unambiguous position in space. The specific configuration of these cells builds an internal representation of the environment that allows the animal to know its position with respect to important locations, in other words represent the allocentric space.

However, some experiments, specifically run on place cells, have shown that in some cases the selectivity of firing is partially or totally lost. Foster et al. (1989) investigated the role of motor set for location-dependent firing in freely moving rats and in restrained rats. After the implantation of electrodes in the CA1 region of hippocampus, neurons sensitive to the place and their activation fields were identified. At this point, animals were snugly wrapped in a towel fastened with clips, and consequently could not displace actively. In this condition, there was almost complete suppression of place selectivity in place cells’ activity. The authors concluded that motor set and, in particular, the preparedness to movement strongly contribute to the spatially selective activity of hippocampal place cells.

In a similar vein, Gavrilov et al. (1998) investigated the role of location, movement and directional selectivity in rats that were passively displaced on a mobile robot. At variance with the previous study, in which the test in restrained condition was conducted only with previously identified place fields, in this case the robot (and the rat on it) followed standard trajectories starting from each corner of a square arena, thus covering an area much broader than the place field.

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Results showed that there was a smooth gradient of position selectivity in hippocampal cells' activation. On the one hand, these data are not in accordance with the results obtained by Foster et al. (1989), where the place selectivity disappeared; on the other hand, with the data obtained with unrestrained rats, in which small and circumscribed regions of the environment were associated with place cell firing.

These studies were meant to investigate the contributions of, respectively, preparedness for movement and vestibular contributions to place cell activity, but their methodology opens new perspectives on the investigation of place cognition, aiming at exploring not only the specific pattern of responses of place and grid cells, but also the role of the animal's active performance of the task.

The aim of the present simulation study was to test the plausibility of the hypothesis that place cognition might depend on the organism's active exploration of the environment.

If so, the results reviewed above, suggesting an important role of the movement in determining the selective firing of place cell, could be ascribed to the active perception of the world performed by the artificial organism, i.e. an evolved robot, rather than to the movement itself. Through action, animals can modify their pattern of stimulation, thus affecting the neural responses that result in the next action. The validity of this hypothesis is difficult to assess with natural organisms, because it is virtually impossible to control all the potential sources of information (visual, olfactory, vestibular, proprioceptive, sense of direction, internal compass, etc.). An alternative possibility is to use artificial organisms, whose input patterns can be thoroughly controlled by the experimenter, and whose internal organization can be analysed at a level of detail difficult to obtain with more traditional methods.

## Methods

In our experiments, we used a software simulation of Khepera robot. It has eight infrared sensors around the robot's circumference that can detect obstacles within a range of 3 cm. A round video camera (with a visual field of 270°) is located on the upper part of the robot. Khepera moves using two wheels located on either side of its body, each controlled by a motor. For the present experiment, we used a modified version of the "Evorobot" simulator developed by Nolfi (2000)—an environment created specifically for experiments with simulated populations of Khepera robots.

The robot's control system consists of a two-layer, feed-forward Artificial Neural Network in which every input neuron has a direct connection to all the output neurons. From a functional viewpoint, we use different kinds of

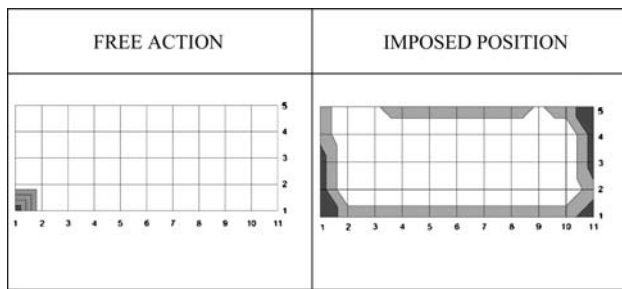
input and output units. The sensory layer consists of a total of 18 units: 2 bias units, 8 close range proximity detectors, and 8 long range detectors of landmarks. The output layer consists of two motor units and one "place" unit.

The behaviour of the robot is determined by the activation of the three output units. The speed of each motor is proportional to the activation of one of the output units. The third output unit (the place unit) temporarily stops the robot whenever its level of activation is higher than 0.5. The activation of the place unit can thus be interpreted as signalling the robot's perception of being situated in a specific location: it is a spatial recognition mechanism.

We used the "blue wall" task, an experimental task used in the study of spatial behaviour (for a review see Cheng and Newcombe 2005). At the beginning of the task, the experimental subject is placed in a rectangular room, with one blue and three white walls. In a corner, the experimenter has placed a very inviting object (a reward). The subject is allowed to see the reward, which the experimenter then hides. After a disorienting procedure, the experimenter asks the subject to find the reward. The geometry of the room and the presence of the landmark define unambiguously which is the corner in which the reward was placed, the one that the subject must move toward and identify.

We used a 568 × 256 cm rectangular arena with white walls except for one long wall, which was blue and thus functioned as a landmark.

The robots were evolved and tested in this arena using a simple form of genetic algorithm. At the beginning of the breeding process, we created the first generation of 100 robots. Each robot had a neural control system with random connection weights. We then tested the ability of each robot to localize the reward area in 100 different trials. At the beginning of a trial, the robot was positioned at the centre, facing in a random direction and was allowed to move around for 1,500 computation cycles. Every time the robot reached and "identified" the target area (activation of the place unit greater than 0.5); it stopped for three computation cycles (500 ms) and received one "reward point". The robot was assigned a final score consisting of the sum of reward points received during all the trials. After all the robots were tested, the 80 with the lowest "reward score" were eliminated (truncation selection). The remaining 20 robots were chosen to survive and reproduce. The neural control system for each selected individual was cloned five times. During cloning, 35% of connection weights were incremented by random values uniformly distributed in the interval  $[-1, +1]$ . These new neural control systems were implanted in 100 robot bodies that constituted a second robot generation. The testing/selection/reproduction cycle was iterated for 100 generations.



**Fig. 1** Maps of activation of the place unit in free action condition (*left column*) and imposed position condition (*right column*) of the best performing robot. *White* represents the absence of firing, *grey* the low frequency firing and *black* the high frequency firing

## Results

The evolved robots prove to be perfectly able to solve the task. They identified in 99.5% of cases the target corner, i.e. the one located in the right position according to the geometry of the arena and to the cue provided by the blue wall.

To understand the type of processing underlying these results, we analysed the activation pattern of the place unit of the best performing individual (i.e. the one which obtained the highest reward score). We examined place unit activity in two different conditions using an observational grid: free action or imposed position. In this latter case, the robot was forced to react to the stimulation pattern associated to every zone of the environment, not only the ones visited during free action. This was obtained by positioning the robot 8 times in each of the 55 cells of the grid, with face directions varying by every 45°. For each trial, the activation of the place unit was registered. Results are shown in Fig. 1.

When the robot is allowed to roam freely in the white arena, the place unit fires exclusively in the reward area. By contrast, when the robot cannot move freely, the place unit is also active in other areas of the arena: the unit activates along the borders of the arena, regardless of the direction in which it is facing. The place unit is never active when the robot is in the centre of the arena. In other words, when the robot is constrained, the place unit becomes an obstacle detector. Thus, the robot's ability to detect the reward area

depends on its ability to choose specific trajectories that brought it to the area without visiting other areas.

## Discussion

In the work described, we studied how place cognition works in a simulated agents: results show that the pattern of responses of the spatial recognition mechanism (place unit) only works in free movement condition, thus sustaining the hypothesis of an Embodied and Situated Cognition interpretation of place cognition. In fact, at least for these simulated agents, knowledge of space cannot be isolated from action. The activity of place and grid cells, often considered the building block and the neural substrate of map-like representation, can be reproduced in a framework of active perception.

This may be considered as an example of what has been called “situated knowledge” (Clark 1997). An explicit representation of the external world in the brain is not the only possibility to explain the huge amount of data in the domain of spatial cognition.

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