Emulating the Functionality of Rodents' Neurobiological Navigation and Spatial Cognition Cells in a Mobile Robot

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Introduction

It is very difficult to emulate in a machine that which comes natural to humans, animals, insects, etc. However, through observation of nature, then simplification by human development standards, which is typically a function of current computer and materials technology, as well as known or developed algorithms and science, are we then able to derive some form of related replication of the natural behavior. That is what we attempt here in a neurobiological inspired navigation and spatial cognition system for a roving robot.

Abstract

A unique roving robot navigational system is presented here, which is inspired by the ***rat's navigational and spatial awareness brain cells***. The rat, as well as all mammalians, are capable of exploring their surroundings when foraging or avoiding predators, and remembering their way home or to the closest known shelter. The robot built in this study, named ***ratbot***, uses characteristics and interpreted functionalities of the specialized navigational and spatial cognition brain cells, which are primarily found in the hippocampus and entorhinal cortex. These cells are the: ***place cells, head direction cells, boundary cells, and grid cells***, as well as ***memory*** used for the storage and access of **salient distal cues**. To navigate from one waypoint to another, the ***ratbot*** uses inspiration from place cells and head direction cells, known as **path integration**. This is accomplished through use of vectors and vector mathematics. Additionally, the ***ratbot*** uses a field programmable gate array (**FPGA**) to emulate grid cell inspired functionality for environment mapping and spatial cognition.

Path Integration

Path integration (PI) was first suggested by Darwin [1], and confirmation this hypothesis, was shown in [2]. Figure 1 illustrates the concept of PI used by animals, as well as the *ratbot*. In this figure, the rat leaves his or her home, travels around the enclosed area until it finds food, then returns home. The foraging/navigation task is accomplished by the rat continuously updating a return vector home approximation from the change in its *head direction*, via **vestibular stimuli**, and *distance traveled* (**proprioceptive stimuli**). Thus, PI is primarily dependent on **internal stimuli**, while **external stimuli** (e.g., visual, smell, etc.) aids in the *correction of growing calculation errors*, which is known as *dead reckoning,* see Figure 2. However, once a path or area has been learned, the need for external stimuli has been shown not to be required in rats [3-5]. Similarly, the *ratbot's* "brain", an Arduino microcontroller board, uses distance traveled information gathered from the *ratbot's* motor **encoders** and the measured change in direction from a microelectromechanical systems (MEMS) based **gyroscope**, for calculating the return distance and direction to home, respectively, see Figures 2 & 3. The *ratbot's* vision (**ultrasonic sensor**) is for object avoidance only. This is similar to a rat foraging in the dark.

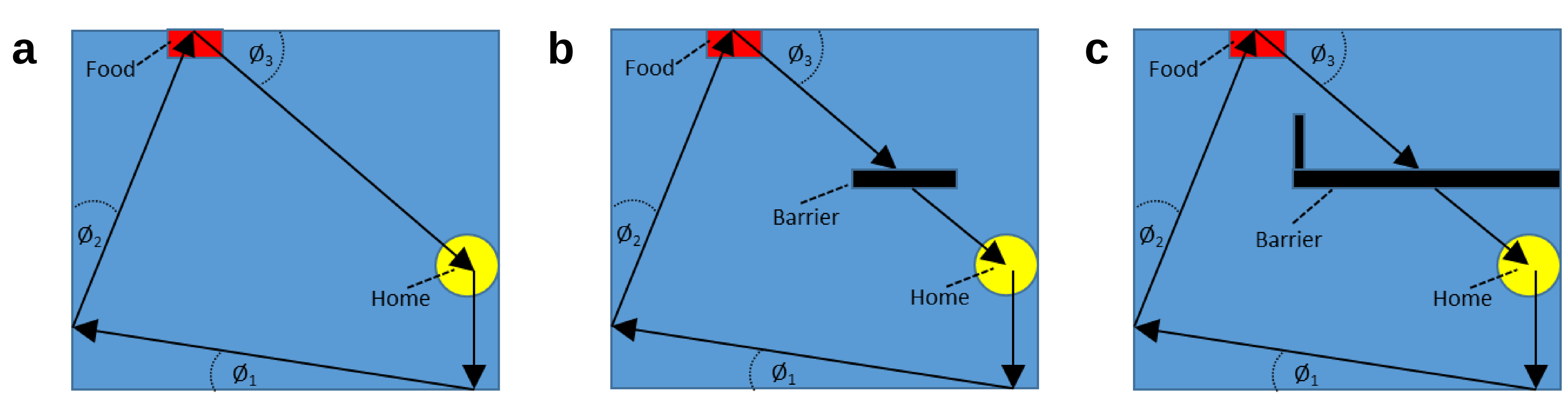

Figure 1: Path integration examples. **a** illustrates the typical scenario found in literature for PI, while **b** and **c** illustrates possible scenarios a rat (or other) will run into during PI. The barriers in both **b** & **c** can be either known or unknown to the rat.

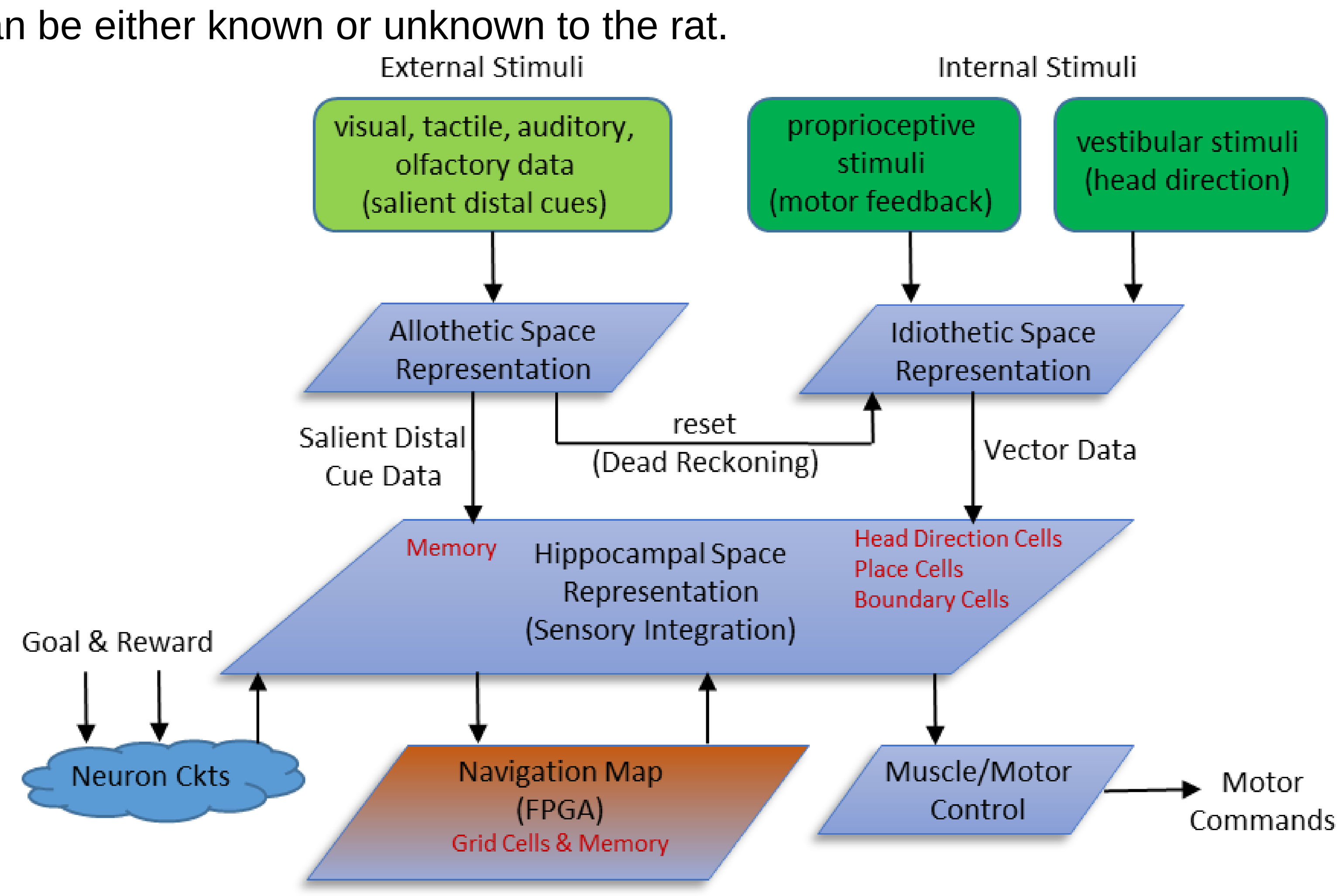

Figure 2: Neurobiological inspired navigation and spatial cognition system for the ratbot.

Spatial Cognition

Through the use of an **FPGA**, the *ratbot's* environment is *logically* mapped into a two dimensional array of parallel processing units, Figure 2. Each unit is an instantiated grid cell's firing location/region, see Figure 4a. In a rodent or any mammal, a single grid cell fires whenever the animal has crossed (or stopped on) a spot that the animal has visited before. The firing regions make a hexagonal lattice shape, which is constructed of equilateral triangles. This is better seen on the on the autocorrelogram, shown in Figure 4b. Each vertex of the equilateral triangle is a particular firing node or region. **The hexagonal lattice firing locations of a single grid cell covers the entire local environment that the rat is currently exploring**.

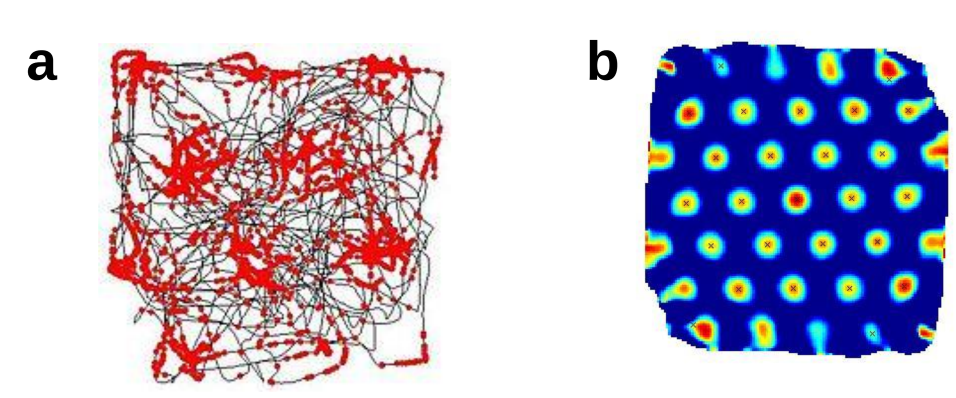

Figure 4. a) Recorded firing locations (red dots) of a **single grid cell**, as a rat explores (black line) a square, enclosed area. Such recordings are obtained by installing an electrode in a rat's cerebral cortex (dorsomedial entorhinal cortex or dMEC), where it picks up the firing of a single grid cell as the rat moves around his enclosure. **b)** The autocorrelogram of the firing data for the grid cell. The hexagonal pattern of the firing locations can be seen in both parts **a** and **b** of the figure [6].

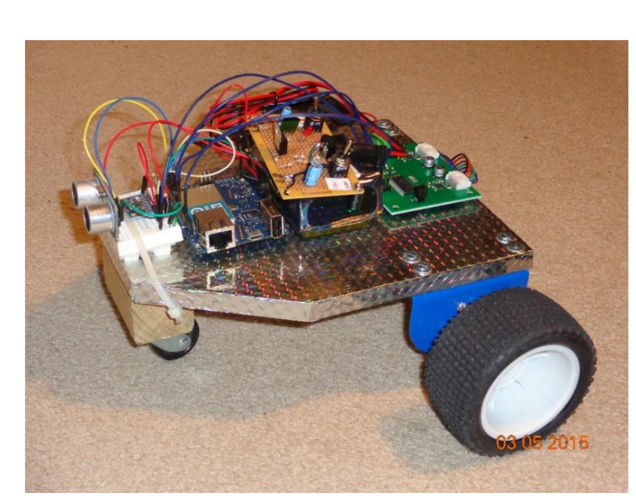

Figure 3: The *ratbot*.

References

[1] C. Darwin, "Origin of Certain Instincts," *Nature,* vol. 7, pp. 417-418, 1873.
[2] H. Mittelstaedt and M.-L. Mittelstaedt, "Homing by path integration," in *Avian navigation*, ed: Springer, 1982, pp. 290-297.
[3] T. Hafting, M. Fyhn, S. Molden, M.-B. Moser, and E. I. Moser, "Microstructure of a spatial map in the entorhinal cortex," *Nature,* vol. 436, pp. 801-806, 2005.
[4] B. L. McNaughton, F. P. Battaglia, O. Jensen, E. I. Moser, and M.-B. Moser, "Path integration and the neural basis of the'cognitive map'," *Nature Reviews Neuroscience,* vol. 7, pp. 663-678, 2006.
[5] A. Arleo and W. Gerstner, "Spatial cognition and neuro-mimetic navigation: a model of hippocampal place cell activity," *Biological Cybernetics,* vol. 83, pp. 287-299, 2000.
[6] http://en.wikipedia.org/wiki/Grid_cell