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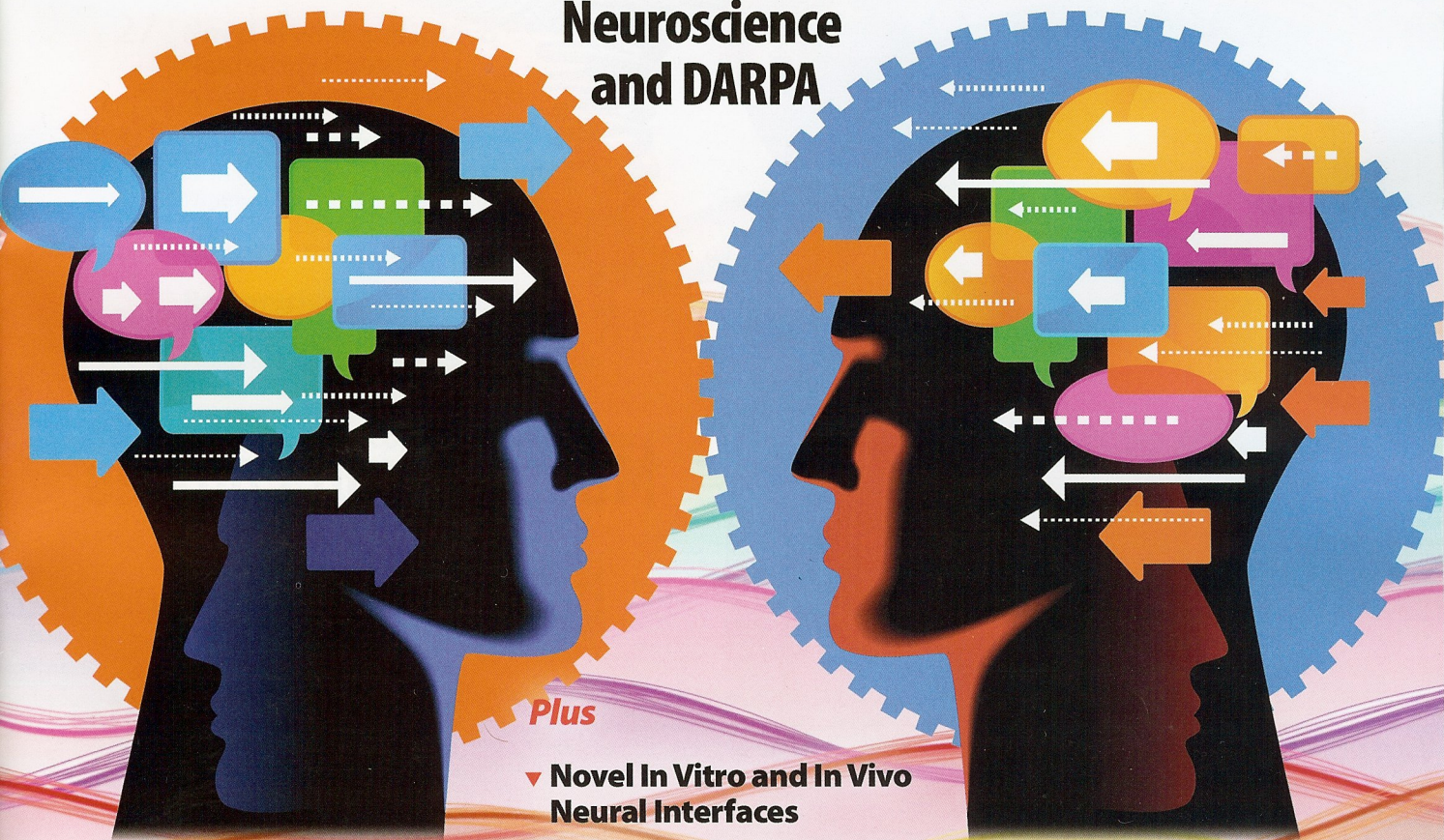Boston University
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The Animat - New frontiers in whole brain modeling

Heather Ames, Ennio Mingolla, Aisha Sohail, Benjamin Chandler, Anatoli Gorchetchnikov, Jasmin Léveillé, Gennady Livitz, and Massimiliano Versace

Abstract—**Researchers at Boston University (BU)'s Neuromorphics Lab, part of the NSF-sponsored Center of Excellence for Learning in Education, Science and Technology (CELEST), are working in collaboration with engineers and scientists at Hewlett-Packard (HP) to implement neural models of intelligent processes on the next generation of dense, low-power, computer hardware that will use memristive technology to bring data closer to the processor where computation occurs. The HP and BU teams are jointly designing optimal infrastructure, simulations, and software platform to build an artificial brain. The resulting Cog Ex Machina (Cog) software platform has been successfully used to implement a large-scale, multi-component brain system able to simulate in a virtual environment some key rat behavioral results, and has been applied to control robotic platforms as they learn to interact with their environment.**

Index Terms— **neuromorphic computing, memristors, large scale simulations, animat.**

I. INTRODUCTION

Throughout the last century, people have speculated about whether or not machines would be able to think, learn, or behave in a human-like way. Attempts to build thinking machines have had limited success to date. Many machines appear to behave like humans on specific tasks, but completely fail when faced with unexpected situations because they are unable to learn when they encounter new environments, stimuli, or tasks. This situation is confounded by the problem that no one really knows how to build an artificial brain, because we are not fully sure how our own brains work.

In the past few years, however, there have been advances in many fields of research that might lead to the building of an intelligent electronic brain. Neuroscience researchers have observed learning at the level of a single synapse and have gained considerable insight into how learning occurs at this scale. Psychologists have looked deeply into learning and

behaviors in humans in a wide variety of tasks and have also used other mammals such as rats to help with understanding intelligent behaviors. Computational neuroscientists have developed increasingly sophisticated neural models to describe both the underlying neural mechanisms and their resulting behaviors. Engineers have been hard at work developing new computer hardware that will allow for many more computations to be performed in a shorter amount of time – all while consuming less power.

One key hardware development is the advance in understanding memristive devices. Memristive devices are two-terminal, nonlinear, passive electrical components that change their resistance as a function of the voltage history. The technology offers potential benefits of much higher memory density, lower power consumption, and compatibility with existing chip manufacturing processes. Eventually, memristive devices may find a use as direct analogs to biological synapses in neuromorphic hardware, but even as a memory technology in a more conventional digital processor, memristive technology will dramatically increase performance and power efficiency.

These devices have allowed for renewed hope in the artificial brain race, because they show promise in changing the architecture of computer circuitry. Memristive materials are compatible with complementary metal–oxide–semiconductor (CMOS) processes, the standard technology for integrated circuits, thus allowing for designers to couple dense, memristive memories with conventional and widely available chips. This is truly an enabling technology for building artificial brains, because the close proximity of memory and computation is a key reason why biological computation is so efficient.

II. THE MODULAR NEURAL EXPLORING TRAVELING AGENT - MONETA

In the past two years, the BU team has developed a novel modular approach in building the neural models that power an artificial brain. The macro-structure of the brain is initially specified with the goal of being able to "swap in" more refined neural circuits when they become available. Modules are currently being developed with increasing complexity and plugged into the architecture, such that the artificial brain system will increase in its functional capabilities as development progresses. This whole brain system is called MoNETA (Modular Neural Exploring Traveling Agent, Figure 1, bottom; [2]) and it runs on a special operating system called *Cog Ex Machina* or *Cog* for short [3], which is designed to
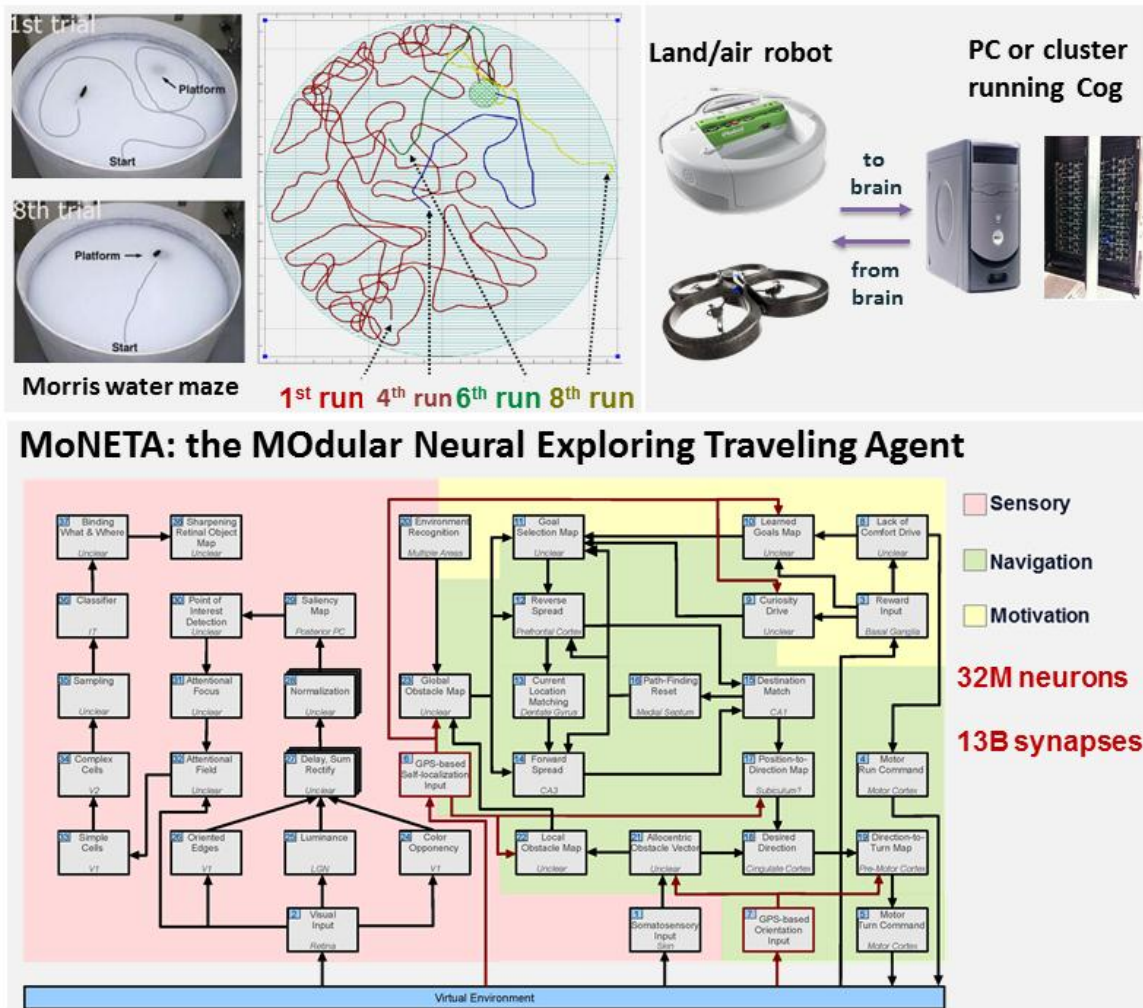
Fig. 1. *Top left*: MoNETA learns to perform the Morris Water Maze task, a typical behavioral paradigm where a rat learns the position of a submerged platform, and is able to swim to it with progressively more direct trajectories when dropped in the water tank. In the first trial, MoNETA explores its environment driven by simulated motivational states, or drives, representing the biological equivalents of lack of comfort and curiosity. Once it by chance swims on top of the submerged platform (green), MoNETA learns its position by using some visual landmark at the border of the pool. As training progresses, MoNETA is able to swim directly from its current position to the platform. *Top Right*: MoNETA can be run on robotic platforms both land and air, by wirelessly interfacing the robot to a workstation of a cluster where Cog runs the MoNETA brain. *Bottom*: The MoNETA (Modular Neural Exploring Traveling Agent) system diagram. MoNETA is a whole-brain-system model consisting of sensory, motivation, and navigation areas interfaced with a virtual environment or robotic platform. The first version of MoNETA consisted of approximately 32M neurons and 13B synapses

provide a flexible, digital platform for the brain models and neuromorphic hardware to interact in a real or virtual environment. MoNETA uses *Cog* to control an animat, a term defining artificial animals, which can be either virtual simulations or physical robots. *Cog* offers a way for researchers to continue building models quickly at relatively low cost while the development of the underlying technology advances.

The MoNETA visual system as currently used involves parallel *what* and *where* processing streams to simultaneously identify and localize objects, respectively. An example of how MoNETA does this is the use of a "dynamic attentional window" in the *where* system that helps the *what* system to focus on a restricted candidate area upon which to deploy limited attentional resources. Simultaneously, the *what* system, once an object is beginning to be identified, biases the *where* system to explore areas nearby the locus of attention that led to the object classification.

MoNETA has the ability to learn and have higher-level cognitive skills. To achieve this goal, MoNETA has a simulated motivational system, modeled after animal drives, to evaluate the utility of objects in its surroundings. MoNETA implements reinforcement learning models for motivation and reward, which in turn bias how the animat selects goals in the environment. Examples of biological drives are lack of comfort and curiosity towards unexplored spatial locations. At any given time, the simulated equivalents of these biological drives compete to control the motor system and move the animat towards a desired location. In addition, MoNETA learns the physical locations of rewards and punishments via reinforcement learning using feedback from the environment. MoNETA then uses the current location and learned goal location to approach the goal via bidirectional graph search that determines the optimal path to the desired location, even in cluttered environments.

MoNETA also integrates sensory information (currently,

vision, touch, and proprioception) into higher order representations of its emerging reality, and is able to react to novel situations not explicitly programmed within the software.

MoNETA v1.0 is completed and has been tested in an animat negotiating a virtual Morris Water Maze task (Figure 1, top left). The Morris Water Maze [1] is a task used to probe the navigation skills of a rodent. In this classic task, the rat is placed in a water tank and has to use visual cues in order to locate a submerged platform and swim to it. The rat is motivated to find the platform because it does not like being wet. Researchers have studied this task at great length, so we know a great deal of the brain areas a rat utilizes in completing the task. Although an apparently simple task, solving the water maze requires the integrated simulation of brain areas subserving object recognition and localization, touch, proprioception, goal selection, motivation, and navigation, among others.

The development of new hardware technologies is still in early phases of research and testing, so MoNETA is powered by simulated architectures that take advantage of a heterogeneous arrangement of computer processors. *Cog* provides the glue between the hardware and the neural models, which in turn allows for seamless integration of new hardware as it is developed.

Success of the animat on the Morris Water Maze task marks the end of the first phase of the project. Initial testing of MoNETA was also done on robotic platforms in a real environment (Figure 1, top right). The next phase will involve running the animat in several other experimental rodent-maze paradigms and expanding the complexity of the neural models powering the animat. In parallel, advances in software and hardware architectures brought forward by our colleagues at HP will bring us closer to being able to implement these models in robotic and mobile platforms.

III. CONCLUSIONS

Although MoNETA is far from a truly thinking learning machine scalable to human intelligence, it does represent an important first milestone in the development of such an artificial brain. It models biological brain functions, it is able to replicate rodent behavior in a simple paradigm, and it takes into account new and vibrant advances in hardware that come closer to mimicking biology than ever before.

ACKNOWLEDGMENT

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