SLUGBUG: A TOOL FOR NEUROSCIENCE EDUCATION
DEVELOPED AT IGUANA ROBOTICS, INC.

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With the current media attention on the intricacies of the human brain and how it functions, the general public seems poised to learn more about the brain sciences. Without a doubt, young people need a working knowledge of basic neuroscience concepts in order to make informed decisions about drug abuse, mental illness and personal health. Iguana Robotics has created "SlugBug," (Figure 1) an effective resource for teaching a diverse audience about the brain sciences. Robotic models can create a vivid understanding of the operation of the nervous system within behaving animals. The specific aim of this research is to develop a small, inexpensive robotic device and associated course curriculum. Combined, this technology will be a powerful tool for University as well as middle, high school instruction in the brain sciences.

This project is highly innovative. We have developed a simple system that can illustrate the connection between integrate and fire neurons (composed of resistors, and capacitors as analogs of neural elements) and behavior. We have converted technology that is used in only a handful of labs worldwide, into a useful mass distributed learning tools.

Further, from a philosophical perspective, this project is profound. We can begin to elucidate how a system of simple elements can give rise to behavior and have students understand this on a visceral level. There is no need to invoke mystical or imprecise notions to explain how an animal generates a behavior. We take the black-box that is the brain, and give students a tiny glimpse of what may be inside. Thus, we do not need to invoke a mind/body duality to explain behavior.

Figure 1. The SlugBug Robot prototype II. The SlugBug is controlled by a neuronal model, implemented with analogues of synapses (real resistors), membranes (real capacitors), and ion channels (real transistors), implementing spiking neurons. The neurons then are linked to behavior by controlling two motors on the robot that make the robot walk.

Students tested with this prototype show a remarkable level of interest and excitement in the robot.

EDUCATIONAL ROBOT RESEARCH

As we believe strongly in the value of robots as tools for science education, we have invested time and resources in initial development of an inexpensive robot body and as well as a highly innovated hardware neuron simulator board that emulates the basic computational components of a neuron: Axon hillock, synapses (inhibitory/excitatory) with synaptic time-constants, membrane potential, and driving potentials.

ROBOT SUMMER CAMPS:

Enthusiasm grows-- Iguana Robotics employees executed a week long robot day camp at the Orpheum Children's Science Museum, Champaign, IL., in June 2004. This event received small amounts of funding from NSF (Research Experience for Teacher supplemental awards) and the local chapter of Institute for Electrical and Electronic Engineers (IEEE). The plan was to bring working biorobot sets for the children to play with and observe their reactions. The camp was a huge success, in the opinion of the museum staff, with parents and campers requesting more time with the robots and more hours of instruction. In 2005, the Orpheum Children's museum requested that we conduct two weeks of camp. Further, the Central Illinois Chapter of IEEE offered unsolicited funds to cover the costs of materials and supplies, giving us $2000. All of this work has provided Iguana's Educational staff with valuable information about the nature of kids and robots.

CHICAGO MUSEUM OF SCIENCE AND INDUSTRY

Iguana Robotics was contacted by the Museum of Science and Industry in Chicago; they were interested in using our biorobots in an exhibit and our assistance in setting up a robot history exhibit. Iguana demonstrated SlugBug robots as well as other research projects at the opening of the "Robots Like Us" exhibit in June 2005. Further, Iguana research robots TomCat and Little RedBot are on loan to the museum for the exhibit.

PILOT STUDIES IN MIDDLE SCHOOL- A preliminary pilot study examining the logistical practicality and student attitudes towards the SlugBug Neuroscience unit was conducted at Edison Middle School in Champaign, IL

Figure 2. Iguana Robotics' volunteer Luda Yafremava demonstrates the SlugBug to students at the Orpheum Museum's 2004 Robot summer camp. Ms. Yafremava is a Neuroscience graduate student at the University of Illinois and did much of the lab work in developing the prototype SlugBug. We base our CPG circuit on the tritonia swim circuit she is investigating as part of her Doctoral Program.

Ms. Yafremava has volunteered hundreds of hours on this project, a testament to her enthusiasm for this project and her commitment to educational outreach.

in October, 2004. Edison Middle School is a racially diverse public school with 30% African American, 6% Hispanic, 5% Asian, 1% Native American and 59% White. The test population consisted of 21 sixth grade students, 9 girls and 12 boys, from the school's enrichment program. Lessons met 50 minutes daily for eight, consecutive school days and were taught by Iguana staff.

Students had an overwhelmingly positive response to the neuroscience unit. During lab work with the biorobot, one student yelled out, "Its alive!" when she probed her SlugBug brain and heard spiking neurons. Another student called out excitedly from the window to our team member as she was approaching the school building, "Mrs. Rogers, are we a goin' to build them neurons today?"

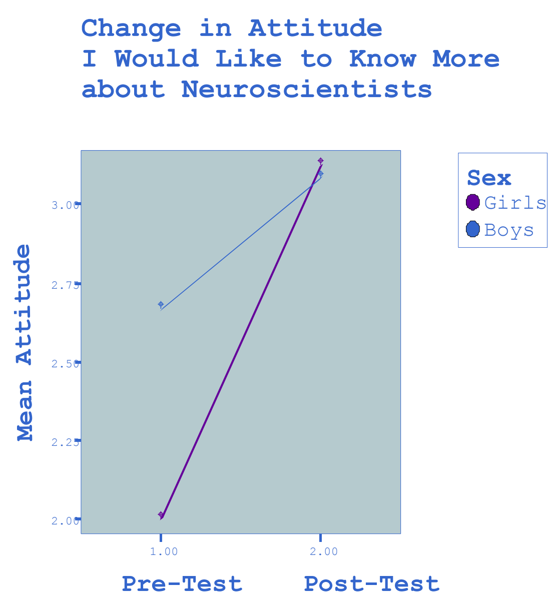

Figure 3.

Students were given a pre and post attitudinal test looking for a change in attitudes and results were remarkable. For example, when asked if they would like to, "know more about neuroscience" after the SlugBug unit, student attitude improved dramatically when compared to the pretest. Female students saw a more dramatic increase in attitude with no significant difference from the males in the post-test (see fig. 3) When asked if "being a neuroscientists would be fun?" Female students once again showed a striking increase in positive attitude after the unit when compared to the pretest. These findings support the results of thesis work done by J. Rogers where female students were found to hold a more positive attitude towards careers in robotics than their male counterparts.

This was preliminary pilot study and an informal survey of a small population. Lesson materials, SlugBug kits and procedures were tested and found to be practical and functional. Clearly, further studies of the SlugBug Neuroscience Unit looking more closely at learning outcomes need to be conducted in order to declare positive results. We see this pilot as an indication of positive outcomes in the future. This work was published as a poster presentation and abstract at the 2004 Society for Neuroscience (SFN) conference in San Diego.

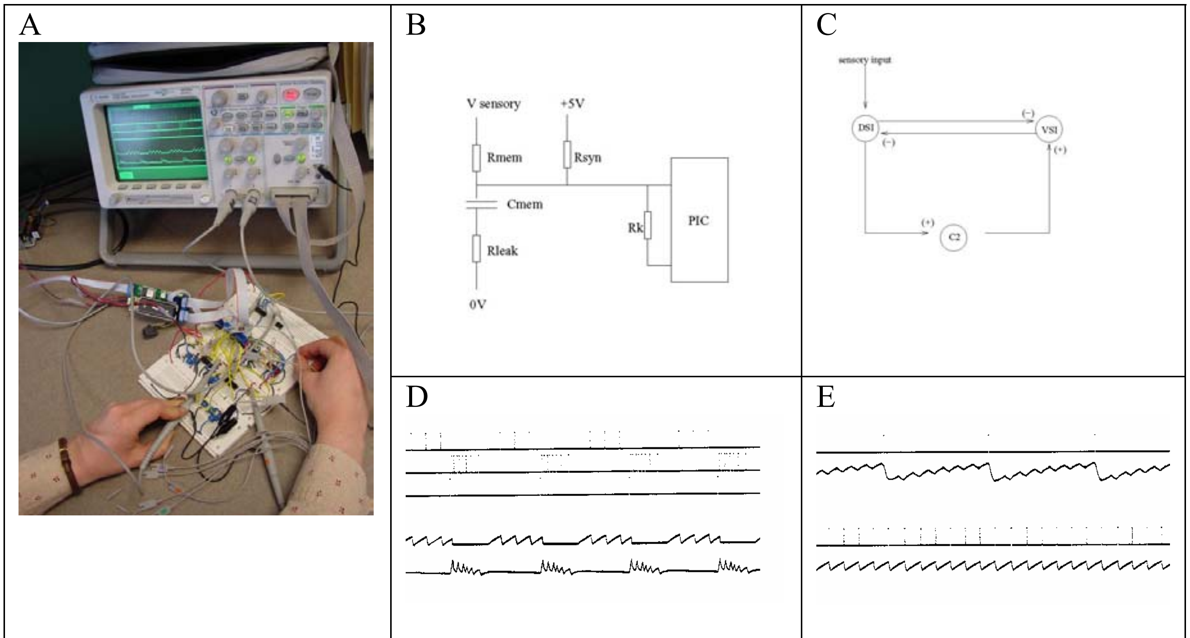

Figure 4. The neuron board. A breadboard version of neuron board. B. Schematic model of a single neuron showing a capacitor mimicking the cell membrane, resistors (conductances) synaptic inputs, and a pic/resistor network comprising the axon hillock. C A simplified version of Tritonia Sea Slug swim CPG [16, 17].(D) Pattern of activity in the swim CPG. Upper trace is the output of DSI neuron. 2nd trace is the output of the VSI neuron, 3rd trace is that of the C2 neuron. 4th and 5th traces are of the cell membrane potential for the DSI and VSI neuron respectively. (E) Synaptic integration. From top to bottom: Spikes from post synaptic neuron, post synaptic membrane potential, spikes, presynaptic neuron, presynaptic membrane potential. This illustrates an epsp as well as synaptic temporal summation.

PILOT STUDIES IN HIGH SCHOOL

Pilot studies were also conducted at the University of Illinois Laboratory School in early 2005. As part of their "Agora Days" celebration, Iguana Robotics presented a four-lesson SlugBug unit. Students built neurons, assembled three neurons into a neural network, and then hooked their SlugBug robots to the simple brains they had constructed. Through small adjustments in the potentiometer/ synapse weight students were able to adjust the SlugBug's gait. The whole SlugBug unit was well received by the students and the science teacher who observed. The Agora event was designed to be an informal learning experience, so students were not given any sort of evaluations.

SLUGBUG AS A TOOL FOR UNIVERSITY NEUROSCIENCE INSTRUCTION

SlugBug robots were beta tested at the annual Neuromorphic Workshop funded by the National Science Foundation. Scientists from around the world come together each summer for a three week workshop in the Colorado mountains. Most scientists who attended the workshop used the SlugBug and found it to be a useful tool. Biologists particularly enjoyed the ease with which the robot's brain could be programmed.

IGUANA'S TECHNICAL ADVANCES IN EDUCATIONAL ROBOTICS

THE NEURON EMMULATOR BOARD

We have developed several iterations of our Iguana Neuron Board (fig.4). This device is scalable and features synapses with adjustable strengths, and "conductance" a membrane potential that can be monitored by a computer or directly with an oscilloscope. Having a hardware system is advantageous, as points on the board correspond to real measurement points in a neuron.

In the future, many lesson plans could be constructed around the board alone. The final board is the size of an index card and is self powered by an onboard battery. A connection to a PC will allow the student to record data from the neurons onto a computer's harddrive for off-line analysis and plotting. In addition, we will have a "smart probe" that will plug into the RS-232 port of a PC. This probe will allow a student to monitor voltages at any point on the board and record this to a PC.

EXPERIMENTS WITH A VLSI CHIP

In related work, we have created a more advanced version of the circuit in Figure 4 which incorporates spike frequency adaptation and implemented in a VLSI chip. The equations for this chip are given by the following differential equations:

$$\tau_{mem} \frac{d}{dt} V_{mem} = -v_{mem} + (V^{+} - V_{mem}) \bullet Syn^{+} + (V^{-} - V_{mem}) \bullet Syn^{-} - fb \bullet \alpha - u \bullet I_{DISCHARGE} \quad (1)$$

$$u = \max(0, V_{mem}) \quad (2)$$

$$Syn^{+} = \sum S_i^{+} \quad (3)$$

$$Syn^{-} = \sum S_i^{-} \quad (4)$$

$$\tau_{syn} \frac{d}{dt} S_i^{-} = -S_i^{-} + w_i \bullet u_i \quad (5)$$

$$\tau_{syn} \frac{d}{dt} S_i^{+} = -S_i^{+} + w_i \bullet u_i \quad (6)$$

$$\frac{d}{dt} fb = u \quad (7)$$

where τ_{mem} =500 ms, the cell membrane time constant , τ_{syn} =100 ms, the synapse time constant, V_{mem} the cell membrane voltage, V^{+}, V^{-} the positive and negative voltage drives.

Intuitively, the membrane is charged by the current in Eqn 1, which incorporates a leakage term, an inhibitory and excitatory synaptic weights and a spike frequency adaptation term.

Using this neuron we have created complex networks as shown in Figure 5 which can generate controllable patterns of activity (Figure 6) sufficient to drive a bipedal robot (Figure 7).

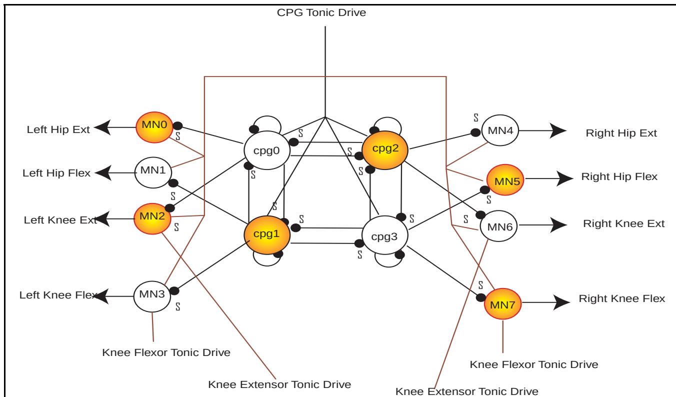

Figure 5. Complex Neural networks have been built around the neuron define in equations 1-7 and implemented in VLSI circuits.

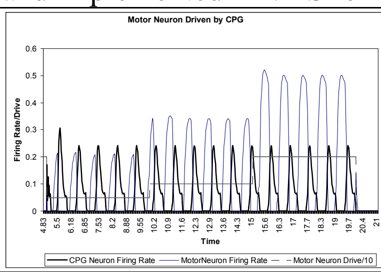

Figure 6. An example of motor neuron output from these neurons. The motor neuron is non-spiking.

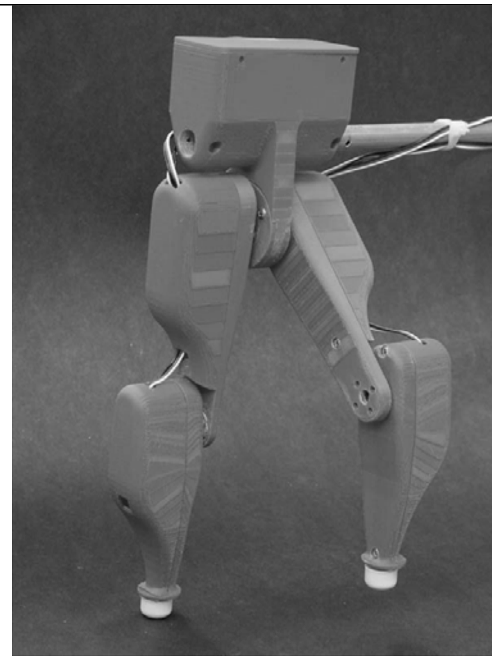

Figure 7. A small biped 30 cm high that trots at about 1 meter/sec using the network given in Figure 5.