THE PUBLICATION OF THE NEUROSCIENCES INSTITUTE

BrainMatters

Spring/Summer 2010

Brain-Based Devices:
A Remarkable Journey of Discovery

2 | Note from the Director

If someone were to ask me what single word encompasses progress in biological science over the last several decades, I would reply "complexity." From the molecular signals within cells to the organization of the brain, we are confronted with causal networks made up of myriad components. In itself, this is no surprise: evolution over vast periods of time selects for increasing numbers of adaptations. Simplicity emerges from time to time but, in the absence of design, only successful elaborations will survive.

When confronted with complexity, scientists use models to understand the relationships and interactions of the components of complex systems. They do this knowing that such models by no means exhaust possible descriptions of the systems they are studying. Nonetheless, models yield insights otherwise not easily attainable.

Work at the Institute has focused on a variety of models. Among the most productive of these has been the construction of brain-based devices. These models consist of simulated brains embodied in mobile devices that can explore a real-world environment. This work has led to major insights into how brain systems result in actual behavior, learning, and memory. Success in this work has already led to basic insights into brain function. Perhaps the most exciting long range impact of this approach will be the development of new devices able to interact with powerful computers to yield a deeper understanding of environmental challenges that are themselves the products of complexity.

Dr. Gerald M. Edelman

IN THIS ISSUE

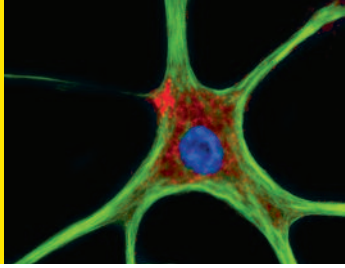
EDITORIAL CREDITS:
Jeanna Adams
Jessica Colby
Einar Gall
Joe Gally
Debbie Honeycutt
Rachel Jonte
George Reeke
Bob Ross

PHOTOGRAPHY:
Einar Gall
Michael Hanna
Jack Foster Mancilla
Bob Ross

DESIGN:
Bernard Groefsema

PRINTING:
Master Print Communications

3 | Brain-Based Devices: A Remarkable Journey of Discovery



We are all inventors, each sailing out on a voyage of discovery, guided each by a private chart of which there is no duplicate. The world is all gates, all opportunities. Ralph Waldo Emerson

A brain-based device (BBD) was born two decades ago, not of flesh, bone, and brain, but rather a device designed to model as closely as possible the embodiment of a living, thinking organism. It was a relatively diminutive device—physically not much larger than a fire hydrant—but it and its successors have led researchers at The Neurosciences Institute on their own remarkable voyage of discovery, one that is helping unravel the mysteries of how animals and humans perceive, behave, and learn.

Conceived in the imagination of Institute Founder and Director Gerald M. Edelman, M.D., Ph.D., and then created and nurtured by a team of pioneering scientists and engineers, these BBDs have evolved to a point today where they not only contribute to our understanding of how the brain works, but also they may soon have practical applications.

In those early days when Edelman first envisioned BBDs, however, he had one specific goal in mind: to develop a new way to explore the brain that would complement and move beyond the traditional experimental techniques that have been, and continue to be, immensely effective in studying the biological bases of brain function.

"While there is no substitute for basic neurobiological research, and its value is undeniable, we often hit a wall because we couldn't—for ethical or technical reasons—study in sufficient detail how the brain functions in living animals and especially humans," Edelman says. "I theorized that by creating a real-world device that simulated the exact structure of a brain working in real time we could begin to test ideas about brain processes in ways often not feasible in laboratory experiments with biological material."

Utilizing what Edelman calls "synthetic neural modeling," the Institute's BBD team has created a series of small portable figures that are at the forefront of computational neuroscience. They rely on advanced computer methods to synthesize complex neural systems from realistically simulated components, each patterned after elements in real nervous systems and operating according to physiological principles.

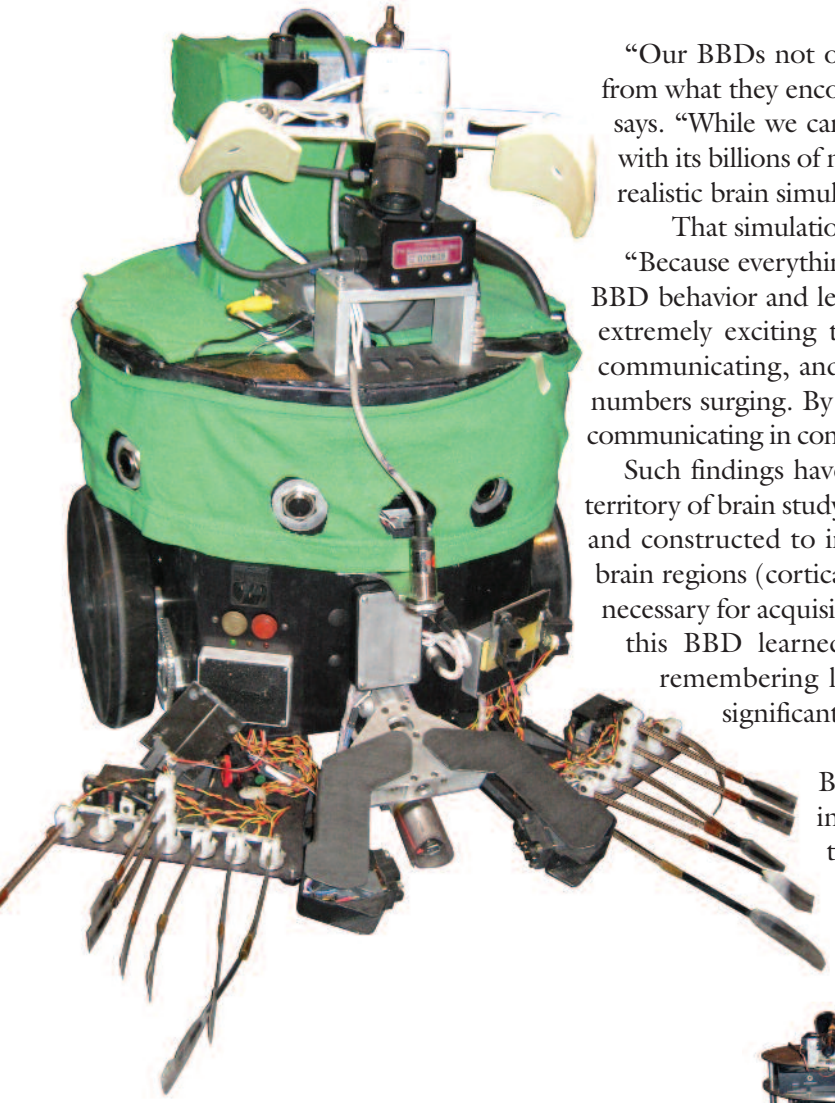
What Edelman and his team were not out to create were robots, a name inadvertently and incorrectly used by many who have seen the Institute's devices. While BBDs may have robotic bodies, they are in fact intelligent learning machines designed on biological principles that alter their behavior to the environment through self-learning. Robots are impressive but have limited capabilities because they can only rely on what has been programmed into their systems and cannot react to the constantly changing conditions of an endlessly complex world.

"You could liken the capabilities of BBDs to those of an accomplished improvisational jazz pianist who can react and shift gears instantly based on changes in his environment, such as those created by fellow musicians," Edelman says. "Most robots, by comparison, are similar to a modern player piano. The piano will play beautifully, and serve a functional purpose, but it will never play anything better or different than the musical notes embedded in its system."

The Institute's first BBD was developed in the late 1980s. It learned from its experiences using its simulated brain called Darwin, which incorporates principles of vertebrate brain organization. The Institute's BBDs have become more sophisticated over the years. They have been equipped with auditory sensors, a video sensor, ultrasonic range sensors, a gripping device with electrical conductivity "taste" sensors, and sets of "whiskers" that feel when the device contacts objects in its environment.

Although some low-level controllers reside in the devices, the main control in each is through a nervous system simulated in an array of computers with which the device communicates over a wireless connection. Each simulated nervous system integrates various sensory inputs and responds by issuing motor control commands that are carried out by the device. The BBDs navigate through their environments, sense obstacles, avoid bumping into them, approach objects viewed from a distance, grab objects with their gripper, "taste" objects, and avoid objects that they have learned "taste bad."

These behaviors alone are impressive in their own right, overshadowing even some of the most advanced robots. The real stunning thing is what we are learning about the brain through these activities.



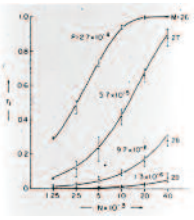
"Our BBDs not only react to their environment, they learn and remember from what they encounter and experience, just as a real brain would," Edelman says. "While we can't make these devices as complex as a living human brain with its billions of neurons, it often turns out we don't have to. We can achieve realistic brain simulation with as few as a million synthetic 'neurons'."

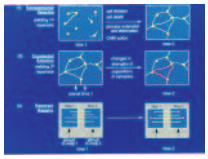
That simulation has led to some groundbreaking results.

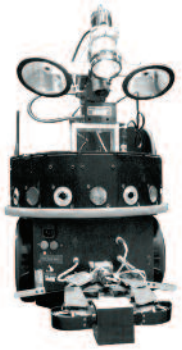
"Because everything is recorded and stored, we can watch the progression of BBD behavior and learning ability by looking backwards," Edelman says. "It is extremely exciting to trace back 200 milliseconds and observe six neurons communicating, and then look back 400, 600, 800 milliseconds and see the numbers surging. By the time we get to 1.2 seconds, thousands of neurons are communicating in complex patterns unique to each BBD and its specific behavior."

Such findings have enabled the Institute to delve deeply into an uncharted territory of brain study. One of the most recent BBDs—Darwin X—was designed and constructed to incorporate aspects of the hippocampus and surrounding brain regions (cortical areas for vision, space, and self-movement) known to be necessary for acquisition and recall of spatial and episodic memories. Over time this BBD learned to successfully navigate its way through a maze by remembering landmarks in its path, an accomplishment that may have significant applications for understanding human memory.

Those are just a few examples of the unique insights the BBDs are providing. Today, as the pace of the effort increases and more of the neural puzzle pieces are put together, the Institute's scientists are beginning to sense the immense potential of this research technique used in concert with the traditional biological research at the Institute. It is this dynamic between the theoretical and







1981
Darwin I
Demonstrates pattern recognition

1982
Darwin II
Neural connections/ categorizations

1990
Darwin III
Simulated organism in the real world

1992
Darwin IV
Learning by conditioning in the real world

1998
Darwin V
Pattern selection by self-generated movement

2000
Darwin VI
Role of history in perception; see, perceive, act

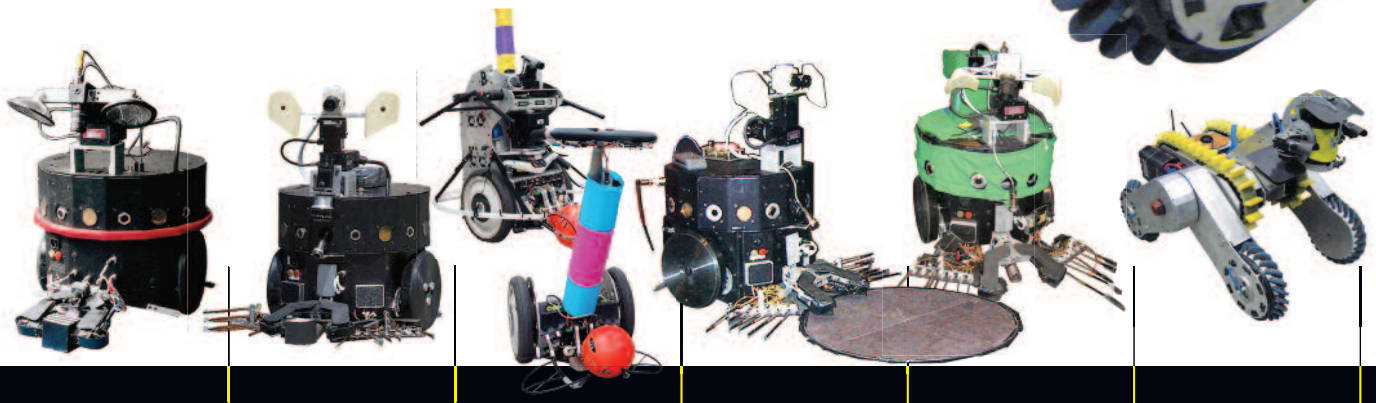
2002
Darwin VII
Vision and hearing combined for conditioning

EVOLUTION OF BRAI

the experimental that promises to open the doors of our knowledge of the brain and brain-based devices.

Edelman and his BBD team believe the devices may eventually help them gain insight into how animals control their movements and thoughts. This could contribute to an understanding of the biological bases of motor movement diseases like Parkinson's, childhood disorders like autism and attention-deficit syndrome, addictive behaviors, and hopefully even something as complicated and mysterious as Alzheimer's. In turn, those types of discoveries could help the scientific community develop new drugs and therapies to treat these conditions. The ability of BBDs to extend human capabilities and function in alien environments could also play roles in making our country and the world safer and exploring new worlds.

"In what could be likened to a Darwinian progression, BBDs have steadily evolved into a singular platform for brain exploration," Edelman says. "The knowledge we are gaining from these devices is increasing exponentially now, profoundly increasing our understanding of the most complex organ in the universe while generating a host of practical applications that could be of enormous benefit to humans."



2004
Darwin VIII
Synchronization in signaling

2006
Darwin IX
Tactile sensing

Darwin Segway
Robo-Cup America Open 2005, model of predictive thinking

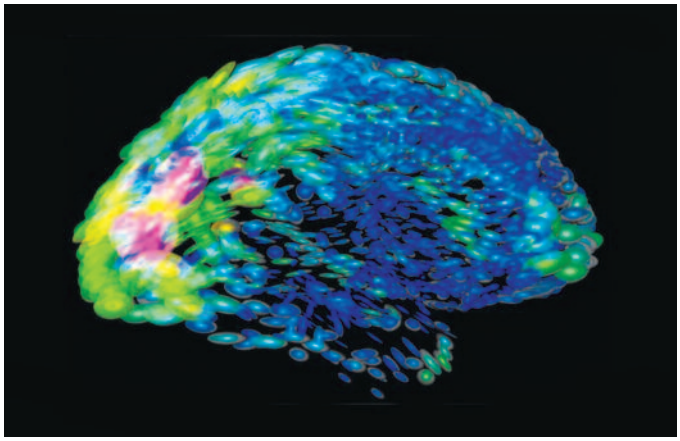
2007
Darwin X
Development of episodic memory

2008
Darwin XI
Development of maze memory

2009
Darwin XII
Ability to navigate outdoors

2010
Coming Soon! Exciting New Work

6 | Building a Brain: A Group Effort



Several unique features make the Institute ideally positioned to produce major breakthroughs in understanding the brain. One of these is its collaborative atmosphere which includes small focused groups that meet regularly to discuss important thematic questions about the brain. We bring people with different talents, backgrounds, and disciplines to work together as a team to solve scientific problems. Our small size and reliance on unrestricted funding allows us this privilege.

One such group is focused on building a brain model to test our experimental scientist's theories of how the brain functions in the real world and to create a thinking machine. This group includes our research Fellows involved in understanding the connections between the brain, body, and environment, which is the primary objective of our Brain-Based Device (BBD) project. These Fellows tackle the complicated task of embodying a brain model and embedding it in the world. They employ groundbreaking methods in this endeavor and have created the first non-living thing that can learn. Here are some observations from a few of these dedicated individuals. In their own words - what they do, how they do it, and why.

YANQING CHEN, Associate Fellow

What makes the Institute the best place to do your work?

The Institute is a unique place where computational scientists, engineers, and biologists work closely with each other for a common goal, to understand the most complex system of all—the human brain. The interdisciplinary atmosphere here provides rare opportunities to translate our biological understanding of the human brain into something useful. This is exactly the type of research I want to pursue here right now. I hope to build more advanced models of the human brain based upon our increasing understanding of the biological principles, so that we can develop a new generation of true "intelligent" systems some day.

JASON FLEISCHER, Senior Fellow

What is your role in building a brain?

I create computer simulations of how different regions of the brain interact to create behavior, usually in our BBDs. Neural simulations of the signals between individual neurons allow us to explore how real brains work, and provide us with a tool that can be investigated more completely than any real brain can. By using BBDs we can start to explore the ways the body and environment work with the brain to create animal behavior. Most recently I have been working on understanding how the basal ganglia control communication between the thalamus and the cortex regions in the brain. Understanding the interaction between these regions may tell us a lot about how we make choices, learn associations, pay attention to some things and not others, and time and sequence actions.

JEFF MCKINSTRY, Research Fellow

What motivates you to do what you do?

The mind is responsible for all human achievements...and failures. Understanding how the mind works will arguably be humanity's greatest scientific achievement. Constructing a brain-based device with a nervous system homogolous (similar in structure and evolutionary origin) to mammals that can solve complex tasks will help us to understand our highest mental faculties, how we learn and remember, and how consciousness arises. Perhaps one day this knowledge will lead to breakthroughs in understanding ourselves, and could lead to more capable brain-based devices. It is easy to get excited about that!

DONALD HUTSON, Design Engineer

Why are you passionate about what you do at the Institute?

The robotics field is in great need of some major advancement in controlling unmanned devices and as with most of our amazing discoveries one of the keys most certainly lies in understanding how the brain works. The BBDs here at the Institute learn and adapt to real-world obstacles that are encountered in the environment. This is exciting! The data the BBD uses is not just processed with computer programming. It is fed into one of our neural models and we get the opportunity to peek under the hood if you will, to see and compare the neuronal activity with our research in animal biology.

Rich Martin
David Edelman
Einar Gall
Yanqing Chen
Ruggero Scorcioni
Jeff McKinstry
David Rathmann
Jason Fleischer
Jim Snook
Pallab Datta
Joe Gally
Donald Hutson
Gerald Edelman

THE **"BUILD A BRAIN"** GROUP

8 | Reaching out to San Diego Youth, Educational Outreach at the Institute

L-R – 1st place Omar Shahrior, Emcee Dr. Nicholas Spitzer, 2nd place Samvit Ramadurgam

"The brain bee was really a great success and we have a lot of good memories about it. Thank you very much for the invitation and for putting this together."

Parent

2010 marks the second year of the Educational Outreach Program at the Institute. In addition to the many hours volunteered by Institute staff members to local students, schools, and clubs, the Institute also invited students from across the county to participate in the second annual San Diego Regional Brain Bee and Teen Discovery Day & Open House. Later in the year we will work with the organizers of the Life Sciences Summer Institute (LSSI) to host students for a day of job shadowing. We are thankful to Life Technologies for their support of this program again in 2010 and to all the volunteers who made this possible.

SAN DIEGO REGIONAL
BRAIN BEE

High school students at lunch with a neuroscientist

Questions get tougher in Round 2

Teens tour Institute labs

In the Keck Foundation robotics lab

A close-up look at Drosophila melanogaster (fruit fly)

Teen Discovery Day & Open House

"Thanks for organizing this great event. I had an incredible time learning and I learned so much. Everything was planned to maximize my time there. Thanks so much for giving me this tremendous opportunity." 9th grade student

"My daughter had an enjoyable and informative day with you and your colleagues. I think she is quite excited about neuroscience research. Thank you for making this possible."

Parent

To find out more about the Educational Outreach Program contact Debbie Honeycutt at honeycutt@nsi.edu.

INTRODUCING THE NEWEST MEMBER BENEFIT: LUNCH & LEARN AT THE NEUROSCIENCES INSTITUTE!

This special invitation-only quarterly brown bag lecture series is presented by one of The Neurosciences Institute's scientists who share their latest research—direct from the lab. Attendees learn about projects that shed light on topics such as learning, memory, decision making, the power of music, and brain development and then are able to ask their questions in the discussion that follows. Bring your own lunch; beverages are supplied.

"All About Plasticity - Our Brain's Amazing Ability to Adapt"
Dr. Weimin Zheng
Friday, March 26, 2010

"Just Say No, Yes, Or Maybe: How Our Brains Make Decisions in an Uncertain World"
Dr. Stephen Cowen
Friday, June 11, 2010

Remember, membership starts at the Friends level with an annual donation of $250. Don't miss out on the benefits of membership!

JOIN TODAY!

The Institute began its Performing Arts program over a decade ago, providing its Auditorium free of charge to local non-profit organizations for arts and educational programs that enhance the culture of San Diego. This program demonstrates the Institute's commitment to the San Diego community and its belief in the importance of the arts and education to our human culture. It is also a natural complement to the Institute's exciting research studies on how our brains process and respond to music and language.

The 352-seat Auditorium, created especially for the Institute by world-acclaimed acoustician Cyril Harris, is now the venue for more than 100 diverse events presented by nearly 40 organizations each year. Because the Institute does not charge these organizations for the use of the auditorium, these organizations realize extraordinary savings in costly hall-rental fees. The Performing Arts Program directly affects San Diegans by enabling over 20,000 people to experience performances in this remarkable hall.

This program is not without cost to the Institute – each year we must secure funding to offset the expenses of maintenance and upkeep of the Auditorium, as well as needed improvements. The Auditorium and Performing Arts Program is a community treasure that needs to be nurtured and maintained, and the Institute needs financial support to ensure the continuation of this important program. Show your support of this program by purchasing your tickets to Minding the Arts today!

Save the date! Minding the Arts - September 12, 2010

Minding the Arts

Support this program by attending Minding the Arts! This event provides guests with a unique afternoon beginning with a lovely outdoor cocktail reception on the rooftop terrace that features a tempting array of food and beverages from San Diego's finest purveyors. Guests are then further indulged with a private concert in the Auditorium. Tickets are $150 for Friends or $250 for Patrons, which includes preferred seating.

Visit www.MindingTheArts.org for more information or to purchase your tickets today!

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BrainMatters

Spring/Summer 2010

Neurosciences Research Foundation, Inc.
10640 John Jay Hopkins Drive
San Diego, CA 92121

Donor Profile: Susan Borden

Susan Borden came to the Institute with a remarkable range of interests and experiences. She had been the Senior Energy Fellow at the Aspen Institute, the Vice Chairman of Common Cause and of the National Women's Education Fund, the Chairman of the Board of Trustees at Bennington College, and an executive of a Canadian energy company. Her formal academic background was in economics and political science, but her primary avocational interests were in still another realm: What can we really know about the human mind? As a college student she had worked with cognitive psychologist Jerome Bruner and since then, she had developed an amateur's love of the work of Darwin, William James, and Freud. She was convinced that the deepest insights into the human mind were likely to come from understanding the principles of human brain function and then mapping those understandings onto the most interesting things that human beings actually do: telling stories, establishing complex relationships, making music, generating ideas, creating theories, developing institutions.

As Susan tells the story, on a day in 1987, she was on one of her frequent forays to the shelves of the Cornell Medical School bookstore in New York. While perusing the as yet quite small "neuro" collection, she came across a newly arrived book with the riveting title "Neural Darwinism." Inside she read the epigrams, one from Charles Darwin and the other from John Keats. With considerable excitement she bought the book and, she insists, spent the next couple of months reading it and grappling with its implications.

Susan then wrote the author, Gerald Edelman, then, as now, the Director of The Neurosciences Institute. "Luckily," she says laughingly, "I no longer have a copy of that letter. Dr. Edelman wrote back a generous and considered reply to my unquestionably naïve questions. This exchange initiated a correspondence that resulted in an invitation to visit the Institute and talk in person. One thing led to another and before I knew it, we were introducing psychoanalysts, educators, and other students of human nature to these seminal ideas. A little later, I was invited to join the Institute's Board."

"To be a part of this remarkable institution for so long," Susan continues, "has been among the most rewarding of my life's intellectual and philanthropic experiences. These days, it is very rare to find big scientific ideas being pursued in small, supple, non-bureaucratic research settings with great intellectual range but with low overheads, no tenure, and a habit of interdisciplinary collaboration.

A small gift to this kind of institution makes a big difference. A larger one can be transforming."

And she adds, "It is also rare that fundamental scientific research can be so accessible to the rest of us. The Institute's scientists don't stray far from the questions that intrigue most curious people: How do we perceive, how do we remember (and forget), how do we learn, and how do we imagine? The emerging answers to these questions have enormous practical consequences for humans – from learning to creating to aging, in both our private and public lives."