

EyeRover negotiates obstacles, guided by software that emulates the brain.



Minds of their own

Novel neuromorphic chips and software should provide robots with unrivaled perceptual skills

By Robert F. Service, in San Diego, California

Like a miniature Segway with eyes, a robot built from 3D printed plastic does laps around a cubicle here at Brain Corporation, having learned in a matter of minutes to avoid bumping into walls as it roams. As eyeRover scoots away, Peter O'Connor, a staff scientist at the robotics software company, steps

into its route. Using a remote control unit, he briefly takes control of the foot-tall robot and steers it around his feet, much as a parent might help a toddler learn to avoid a coffee table. On the next lap, eyeRover whisks around the obstacle all by itself.

EyeRover may look like a toy, but it's packed with some of the most advanced robotic technology ever devised, including a prototype computing platform designed

to emulate the human brain. Unlike conventional computer chips and software, which execute a linear sequence of tasks, this new approach—called neuromorphic computing—carries out processing and memory tasks simultaneously, just as our brains do for complex tasks such as vision and hearing.

Many researchers believe that neuromorphic computing is at the threshold

of endowing robots with perceptual skills they've never had before, giving them an unprecedented level of autonomy. It "has the potential to be a real revolution" in robotics, says Michele Rucci, a robotics vision expert at Boston University. At the same time, robots could provide the perfect demonstration of the power of neuromorphic computing, helping persuade scientists in fields ranging from computer vision to environmental data analysis to embrace the approach. "We think robotics is the killer app for neuromorphic computing," says Todd Hylton, Brain Corporation's senior vice president for strategy.

IF YOUR EYES ROLL at yet another claim that we are on the cusp of a golden age of robotics, you're forgiven. The dream of autonomous robots predates even the dawn of computing. But it has never been realized because of the difficulty of programming robots to learn and adapt. Decades of work in artificial intelligence, computer architectures, and Bayesian statistics—a technique for weighing the likelihood of different outcomes to unfolding events—have failed to produce robots capable of managing more than a handful of mundane tasks in everyday environments.

Building robots that can make sense of their surroundings is "a particularly tough computational problem," Hylton says. Take vision, the primary way most of us analyze our environment. "Robotic vision is far behind what we promised 20 to 30 years ago," Rucci says.

Teams have come up with various strategies for enabling robots to process and react to what they see (see p. 186). Rucci, for one, has given robots the same type of tiny, involuntary eye movements that humans perform; by providing our brains with constantly shifting images, they help us judge depth and track objects. Still, Rucci's best flitting-eye bots are hampered by their brains, which process information 10 times slower than we do.

The human eye works so well, in part, because of the sheer complexity of the computer inside our skulls. Our brains contain an estimated 100 billion neurons connected by 100 trillion synapses, and they can distribute different perceptual tasks to different groups of neurons and different brain regions, explains Brain Corporation CEO Eugene Izhikevich. In vision, for example, separate groups of neurons respond to vertical and horizontal features and pass those signals up the chain to other neurons that integrate the signals.

Brain Corporation's neuromorphic software, called BrainOS, mimics that approach.

Like our brains, the operating system segregates visual functions into different networks, analogous to the retina, the brain's lateral geniculate nucleus (a relay station for visual signals), and the layers of the visual cortex. Integrating the output of these networks results in a robotic visual system able to focus automatically on salient features that stand out from background, such as a brightly colored ball rolling across a gray carpet or the shoes of a person crossing a robot's path.

Another innovation of BrainOS is that it doesn't require a supercomputer to run. A previous neuromorphic software program, developed by IBM in 2012, did run on a supercomputer, using it to mimic the firing patterns of an animal brain containing 500 billion neurons and 100 trillion syn-

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apses. But even with an array of 1.5 million computer chips, the program couldn't produce those firing patterns in anywhere close to real time.

BrainOS, on the other hand, is integrated into a coaster-sized computer circuit board called bStem (short for "brainstem") that's powered by a Snapdragon mobile phone processor from Qualcomm. Unlike conventional computer chips, mobile phone chips minimize power use by distributing tasks, such as memory, graphics processing, and communication, to specialized sub-processors. That "distributed" architecture dovetails well with the neuromorphic approach.

A truly neuromorphic architecture, with memory and processing elements distributed throughout the chip, may be coming soon. Qualcomm researchers who sit just upstairs from Brain Corporation have built a neuromorphic chip they call their Zeroth processor—named after science fiction writer Isaac Asimov's Zeroth Law of Robotics, which states that robots are not allowed to harm humans. M. Anthony Lewis, who heads neuromorphic computing efforts at Qualcomm, says the company is nearing commercialization of the processor, which they plan to integrate into their mobile chips to improve handheld devices' audio and visual processing skills.

Qualcomm has plenty of competition. Just up Interstate 5, researchers at HRL Laboratories LLC in Malibu are working on their own neuromorphic chip, which they've recently shown can process visual

data fast enough to pilot a palm-sized helicopter inside an office building and recognize and explore rooms it has never seen before. And in August, a team led by researchers at IBM's Almaden Research Center in San Jose reported a titanic neuromorphic chip, dubbed TrueNorth, that contains 5.4 billion transistors wired to behave like 1 million neurons connected by 256 million synapses (*Science*, 8 August, p. 614).

These neuromorphic chips are inspired not only by the architecture of the brain but also by its energy efficiency—the brain, which bests supercomputers on many tasks, uses roughly 20 watts of power. Whereas conventional computer circuits regularly bleed electricity even when they're not sending a signal, neuromorphic circuits use power only when active. And by distributing memory and processing modules throughout the chip, they minimize the power required to send data back and forth during computations. TrueNorth, for example, uses only 1/1000 the energy of a conventional chip to carry out the equivalent visual perception tasks.

Which real-world applications for neuromorphic robots will emerge first? Last fall, Qualcomm engineers demonstrated that a meter-high neuromorphic robot called Dragon could adeptly clean up scattered toys, sorting blocks into one bin and stuffed animals into another. For his part, Izhikevich believes that neuromorphic hardware and software will at long last give robots enough perceptual skills to be valuable home companions: able to take out the trash, clean the house, and pick vegetables from a garden. Neuromorphically heightened perception, adds IBM's neuromorphic team leader Dharmendra Modha, will give robots the wherewithal to navigate hazardous environments, such as a damaged nuclear reactor, without guidance from a human operator, beaming back data on radiation and other conditions in real time.

The energy efficiency of neuromorphic computing could open the way to new functions, Lewis says. Efficient chips can run complex—and normally power-hungry—algorithms that enable robots to learn. The Internet, in turn, will allow far-flung robots to share those lessons and skills. A robot that learns how to pick a strawberry without crushing it, for instance, could uplink that skill for the benefit of its kind around the globe. That means neuromorphic computing could offer robots something far more profound than enhanced perceptual skills. When humans collectively pass along life lessons, we call that culture. ■