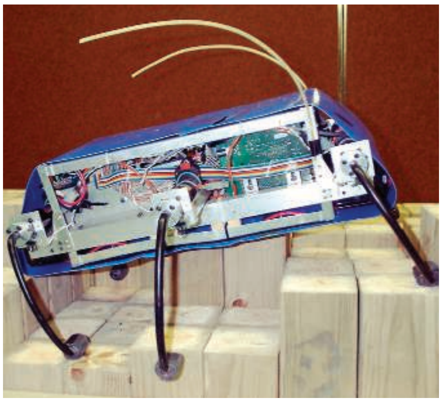
SAN DIEGO, CALIFORNIA—From 4 to 8 January, agile roaches, swimming robots, and digging reptiles demonstrated the synergy between robotics and biology.

Scurrying Roaches Outwit Without Their Brains

To an urbanite, it's a depressingly familiar scene: You flip on the light, and there's a cockroach, zipping across the cluttered countertops, scooting along a wall, and disappearing behind the sofa. Cockroaches are master escape artists. Two studies combining math, engineering, neurobiology, and biomechanics have begun to tease out the secret of this pest's success: conservative use of brainpower. According to the new research, a cockroach taps the brain when sticking close to walls but skips nervous system control during excursions across countertops and other uneven surfaces. "It can go on its own without a lot of sensory input," says Robert Full of the University of California, Berkeley, who led the work.



To think or not. On obstacle courses, cockroaches are on autopilot (upper). But this antenaed robot (lower) has shown that running along walls takes brains.

In 2002, as part of their effort to understand cockroach locomotion over flat surfaces, Full and his colleagues tied miniature cannons onto cockroaches' backs. When they fired the cannon to knock the treadmill-running insects off balance, the researchers discovered that the bugs seemed to recover too fast for their muscles to be controlled by nerves (*Science*, 6 September 2002, p. 1643).

To follow up, Simon Sponberg, a graduate student in Full's lab, tracked the neuromuscular activity of cockroaches as they scrambled through an insect-scale obstacle course. "We usually think about these complicated leg movements as being coordinated neuromuscular interactions," says John Bertram, a biomechanicist at the University of Calgary in Canada.

But that proved not to be the case. Sponberg's colleagues first used mathematical modeling to show that an insect relying on the natural springiness of its legs could run the obstacle course without peripheral nervous system guidance. Next, they modified the control program of a cockroach-inspired robot so that it ran without such guidance; it did fine on an obstacle course. Sponberg then monitored the electrical activity of cockroach leg muscles and the nerves working them as the insects sprinted across both flat and rough terrain. The pattern of electrical activity was the same on both terrains, indicating that no additional neural control is used to navigate complex environments, he reported at the meeting. The work "has revealed that the mechanical system [legs, etc.] is a complex, dynamic system with a mind of its own," says Devin Jindrich, a comparative physiologist at the University of California, Los Angeles.

Such independence simplifies locomotion, as the brain doesn't have to keep track of either the legs or the obstacles. If designed properly, robots too could conserve brainpower, adds Jindrich. "That allows you to free up control for other things that might be more difficult," he notes.

However, brainpower is crucial to running next to a wall, another typical behavior for cockroaches, says Noah Cowan, now an engineer at Johns Hopkins University in Baltimore, Maryland. Cowan recently blindfolded cockroaches, forcing them to use just their antennae for guidance. Using high-speed video of roaches running next to walls, he concluded that the insects monitor the bend of an antenna as it touches a wall. If the antenna bends back too much, the body is heading too close; when the antenna is straight, the insect is too far away. Sensing these differences, the brain signals muscles and adjusts the insect's orientation to the wall accordingly. When he gave an antenna-laden robot that capability, however, it didn't stay close to the wall at all.

After more observations of the live specimens, Cowan realized that a cockroach also factors in its speed. It determines velocity based on how quickly the antenna bends and unbends, input that adds another degree of control for the behavior. With that added feature, the robot excelled as a wall runner. "A combination of these two control systems was absolutely necessary," says Bertram. If only such understanding of how roaches use—or don't use—their brains would make us smarter about catching them.

With Flippers, Two Can Equal Four

Researchers trying to model how a beast that vanished millions of years ago swam through oceans have discovered that more isn't always better when it comes to flippers.

Intuitively, two pair of fins—as in those used by the large, extinct reptiles called plesiosaurs—would be faster than one pair. But then why do many modern aquatic animals usually use just two, with the other two limbs reduced in size or eliminated all together? Seals, for example, evolved from a four-legged terrestrial ancestor but now depend on just modified hind feet for locomotion. Similarly, sea lions use mainly their front flippers.

Using a robot, a team of engineers and biologists has begun to resolve not just how plesiosaurs swam but also the pros and cons of two versus four flippers. Their preliminary conclusion: Two limbs are good for a steady swimmer, and four are better for starts and stops, John Long, a vertebrate physiologist at Vassar College in Poughkeepsie, New York, reported at the meeting.

Long's colleagues Charles Pell, Brett Hobson, and Matthew Kemp of Nekton Research LLC in Durham, North Carolina, designed and built their robot over the past 9 months, dubbing it "Madeleine." She looks a little like a turtle and can swim forward or backward. Each side has a front and back "flipper"—flexible flaps that can move in sync or independently. The robot can roll and wiggle side to side as well as tilt its body up and down. "By simply turning on various combinations [of the fins], they can get different kinds of locomotion,"

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