cues," says neuroscientist Mel Goodale, of the University of Western Ontario, in London. But perhaps the most intriguing aspect of the work, he says, is that the Caltech team found neurons sensitive to object distance, not in the "where" stream, where conventional wisdom suggested it to be, but in primary visual cortex and in V4, which is part of a second processing stream, the "what" stream, which specializes in the identity of objects. This could mean the trait may occur throughout that stream, and perhaps the whole visual cortex.

This invites researchers to "rethink the 'what' pathway" and the role distance information plays in its mission, says Sejnowski. Size is relevant to an object's identity, he says, and the "what" stream would need distance information to compute size. "In retrospect," says Desimone, "it makes perfect sense" that visual maps in the 'what' stream would be three-dimensional. "But honestly," he adds, "I was surprised."

–MARCIA BARINAGA

PHYSICS

First Ticks of a Super Atom Clock

Bose-Einstein condensates have yet to make the leap from quantum toy to tool. But in prodding these curious aggregates of supercold atoms, physicists have elicited some hints of future practicality. Now, a group led by Carl Wieman at JILA and the University of Colorado in Boulder has fashioned a crude clock based on the quantum ticks of these balls of atoms. A much-refined version might one day replace the traditional atomic clocks that keep the world on time.

DAVID DUSSOURD

Today's atomic clocks are pegged to the frequency of light emitted when a cesium atom flips between two slightly different configurations—one in which the spin of the electron and the nucleus point in the same direction, and one in which they point in opposite directions. To get an observable signal, clocks usually watch millions of atoms. With such large numbers, however, the atoms interfere with each other electrically, smearing out and shifting the precise spacing of atomic levels, which blurs the regular ticking.

Condensates offer a way to get more bang for the atom. A condensate forms when a cloud of atoms is cooled to within a hair of absolute zero and all the atoms leap into the same quantum state "like lemmings," Wieman says. Then, it turns out, instead of acting like individual clocks, their pendula swing in perfect harmony, which can amplify the signal manyfold. "That's a huge difference," says physicist Steven Chu of Stanford University.

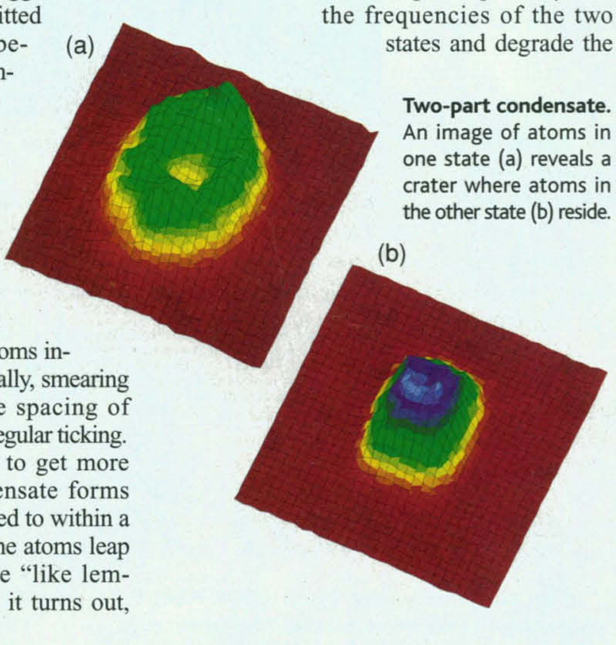
Wieman and colleagues didn't set out to make a condensate clock. Condensates, like all quantum objects, have wavelike properties, and the team was studying how the waves of two condensates interact over time. They confined a few hundred thousand rubidium atoms in a magnetic trap and cooled them into a condensate. Then they split it using a radio frequency burst to form a second, overlapping condensate, in a different spin state from the first.

The quantum waves corresponding to the two states have frequencies that differ by a small but precise amount, just like the two states of cesium that have been used to keep time. The frequency difference can be inferred by allowing the two condensates to interact briefly and watching how many atoms jump from one to the other. The team expected that as the condensates sloshed around in the trap, the frequency difference would get washed out. But when they measured the populations of the condensates with a laser, they found that the frequency difference was durable enough to keep time.

"You can think of this as the first Bose-Einstein condensate clock," Wieman says. But he cautions, "I wouldn't want to push the accuracy [of] it much." Jason Ensher, a member of the team, notes that it is only good to about a billionth of a second—over a million times less accurate than the best atomic clocks.

Another practical limitation of this version is that the laser burst that reads the time destroys the clock. And the magnetic fields of the trap will probably blur the frequencies of the two states and degrade the precision of such a clock, points out Christopher Oates, a physicist at the National Institute of Standards and Technology in Boulder. Condensate clocks may keep time for future generations, he says, but for now the idea is "still in diapers."

–DAVID KESTENBAUM



Two-part condensate. An image of atoms in one state (a) reveals a crater where atoms in the other state (b) reside.

HALL ET AL.

ENTOMOLOGY

Earth's Unbounded Beetlemania Explained

It's a tale every evolutionary biologist knows by heart: Asked what he had concluded about the Creator from studying creation, the great biologist J. B. S. Haldane reputedly quipped that the Creator "had an inordinate fondness for beetles." And indeed, the 330,000-odd species in the order Coleoptera—the beetles—far exceed the number in any other plant or animal group. "It's a saying that's always in the back of your mind," says Brian D. Farrell, an evolutionary entomologist at Harvard University. On page 555, Farrell hands the credit for this diversity to the beetles' own fondness for a leafy diet.

Laying siege. Willow-eating *Chrysomela*, laying eggs, profited from rise of flowering plants.

Although the Coleoptera arose some 250 million years ago, "age alone doesn't explain" their diversity, says Farrell. Instead, his research shows that the appearance of flowering plants some 100 million years ago set leaf-eating beetles on speciation's fast track. "It's a classic case of coevolution," says Farrell. "The plants were like a new, unoccupied island, and the herbivorous beetles were among their first colonizers—that's what opened the door for their dramatic radiation."

To reach that conclusion, Farrell merged paleontology, phylogenetics, biogeography, and plain old natural history. "This kind of analysis is what evolutionary biology is all about," says Harvard's E. O. Wilson. "He's addressed two of the most important problems in the field: what determines the number of species [in each taxon] and why some groups, like the leaf-eating beetles, are just over the top in terms of success." Adds

Thomas Eisner, a chemical ecologist at Cornell University, "It's a classic study. Charles Darwin would be proud."

The first beetles were not vegetarians—primitive beetles living today eat detritus and fungi—but it only took them 50 million years, or as Farrell says, "the evolutionary equivalent of about 50 seconds," to figure out they could survive on cycads, ferns, and conifers. Many of these earliest herbivores dined on the interior sappy bark or stems of such plants, while their larvae munched the nitrogen-rich, pollen-bearing structures inside the cones. Farrell thought that tissue-eating behavior could have prepared certain beetle species for the appearance of the juicy flowering plants, or angiosperms.

The idea that plants and insects might be dancing an evolutionary pas de deux was first suggested in 1964 by Stanford University ecologist Paul Ehrlich and Missouri Botanical Garden botanist Peter Raven. "They had this cool vision early on," says Farrell, "about how plants could be the driving force in insect evolution, and vice versa." The hypothesis made sense because many insects are restricted to feeding on certain groups of plants—and many plants have defenses targeting insects. The idea took a hit 5 years ago, when Conrad Labandeira of the National Museum of Natural History found that the appearance of angiosperms had no effect on the number of insect families (*Science*, 16 July 1993, p. 310). But the picture was different when Farrell applied a finer lens to the most successful insects of all, the beetles.

He analyzed highly conserved DNA sequences from 115 species of the herbivorous beetle subfamilies, sampling up to six species from each, to create a phylogenetic tree showing the likely evolutionary relationships of today's beetles and when they diverged from common ancestors. He mapped his tree on floor-to-ceiling charts hung in his office, compiling onto them data from fossils, species' dietary habits, and the biogeography of present-day beetles to identify which beetle ancestors ate which host plants on which continents and over what time periods. "I felt like a photographer in a darkroom," he says, "watching as the chemicals made a picture emerge."

The developing image revealed a tight link between plants and beetle diversity. While cycad and conifer-feeding beetles formed the family tree's trunk, angiosperm-eaters dangled from the top branches. Two related superfamilies, Chrysomeloidea (such as the Colorado potato beetle) and Curculionoidea (which includes weevils), seem to have benefited particularly from the blossoming of a leafy, green world. Together, their known 135,000 species comprise some 80% of all herbivorous beetles and almost half of all herbivorous insects. And their population boom coincides with the rise of angiosperms. "They show an increase in diversity by several orders of magnitude," Farrell says. "Well over 100,000 new species of beetles arose because of that move to angiosperms."

The findings, says Farrell, "show how moving into a new environment, where there's no competition, can free you for an explosive adaptive radiation." Or, as Eisner pithily puts it, "it shows what happens if you eat your vegetables."

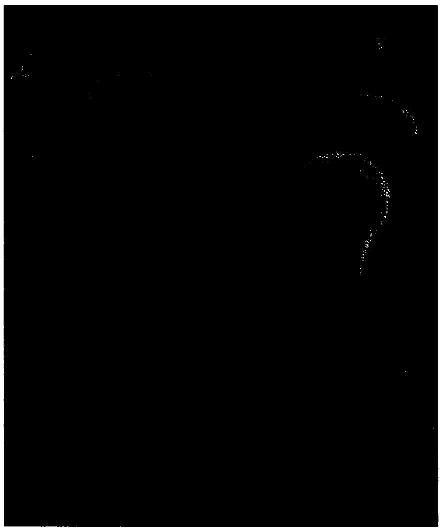
–**VIRGINIA MORELL**

DEVELOPMENTAL BIOLOGY

How Plants Pick Their Mates

Plants don't flirt. They don't gaze too long or blush. They produce flowers but don't show up at the door with a bouquet. Even without such behaviors, though, they are very choosy about their mates and rarely cross-fertilize with other species in the wild. Now, researchers have shown for the first time that the female parts of plants make snap judgments—good ones—about whether they have something in common with the pollen grains on their threshold.

At the Society for Developmental Biology meeting at Stanford University last month, Daphne Preuss, a plant geneticist at the University of Chicago, and her colleagues reported that the receptive female part, the stigma, of the experimental plant *Arabidopsis* grabs pollen of the same species and holds on so tightly that even the sheer force of a centrifuge can't separate the two. But pollen from a different species just falls off. What's more, the stigma apparently discriminates among its suitors by conversing with the cell wall of the pollen grain, a structure most scientists had deemed to be as uncommunicative as, well, a wall.



D. PREUSS

For keeps. Pollen grains (yellow), magnified 600 times, cling to female flower part.

Understanding how plants block inappropriate mating might allow researchers to "overcome those barriers and produce new hybrid crops," says Preuss. "For example, cold-tolerant plants could be crossed with plants that produce high-quality fruits."

Because plants can't move, many are literally at the mercy of the winds for introducing sperm, carried by pollen, to the eggs in the female part of flowers. Factors such as species-specific pollinators ensure that the right pollen ends up in the right type of flower, but pollen from other species often makes its way to the stigma as well. So, the female tissue raises many obstacles to hinder mismatched sperm on its way to the egg, explains Dina Mandoli, a plant developmental geneticist at the University of Washington, Seattle. But the earlier the female foils any interloping sperm, the better, and "no one had looked at the very first step before," she says.

To find out whether the female tissue assesses potential partners upon first contact, Greg Zinkl, a postdoc in Preuss's lab, brushed an *Arabidopsis* anther, which carries pollen, on a stigma. He dislodged unbound pollen by adding a solution containing detergent and centrifuging or vortexing the stigma. Then, he counted the pollen grains still attached—and found that many had made an instant connection. "This is very abusive treatment," says Preuss. "We'd expect things to pop off if they could, but amazingly, the pollen sticks very well." When Zinkl repeated the experiment with pollen from the unrelated petunia plant, the pollen fell off.

When the researchers looked at the plant surfaces through an electron microscope, they saw no physical structures that might explain how the plant parts embrace—no entangling hooks and loops. "Whatever it is has to be very small—some kind of molecular Velcro," says Preuss. "We're at the level of chemistry—not large cellular structures."

Although the group hasn't yet tracked down the sticky molecules, a preliminary search for mutant pollen cells that don't adhere properly suggests that structural defects in the cell wall ruin the attraction. This adds to a growing realization that cell walls play an active role in cell-cell signaling, researchers say. "People have always had this idea that the cell wall is an inert matrix—just cork, boxes that hold cells in place," says Scott Poethig, a plant developmental geneticist at the University of Pennsylvania, Philadelphia. "But it's becoming clear that the cell wall is a playground where a lot of molecules can interact and talk with each other."

Whatever the precise mechanism, it seems that the instant alliance between pollen and stigma is based on surface attraction. But among plants, at least, this type of union sticks.

–**EVELYN STRAUSS**

Evelyn Strauss is a science writer in San Francisco.