Putting their findings together into a single scenario for the *daf-2/daf-23* pathway, Ruvkun's group proposes that during times of plenty, *C. elegans* maintains high levels of an insulin-like hormone, which binds to DAF-2. This, in turn, may trigger DAF-23 to activate the second messenger, passing an "okay to burn fuel" signal to the cell interior. But when the worms grow so numerous that they threaten to overtax their food supply, two things happen: Increased pheromone concentrations trip individual worms' chemosensory alarms, and internal insulin levels decrease, a sign of plummeting glucose availability. The two signals together push the worms into the dauer stage.

Mice fed meager diets may go through parallel physiological calculations, suggests S. Michal Jazwinski, a geneticist studying aging at Louisiana State University Medical Center in New Orleans. The caloric restriction pushes the mice into a high-efficiency state, in which normal 2-year life-spans increase by up to 40%. "They metabolize as much glucose on a per-gram basis as other animals, but they can utilize that glucose more efficiently," Jazwinski explains. As a result, they show fewer of the changes, such as oxidative tissue damage, thought to lead to aging. If human cells could be fooled into making a dauerlike transition to efficient energy use, Jazwinski speculates, it might eventually be possible to soften the ravages of aging.

The existence of a food-sensitive, longevity-inducing mechanism in species as distantly related as nematodes and rodents suggests that nature has long been experimenting with such inhibitors of aging. "You could imagine that in a primitive metazoan, a way evolved for the animal to make it through bad times, and that core regulatory ability still exists in different organisms but is expressed in different ways," says UCSF's Kenyon.

Ruvkun speculates that the high incidence of diabetes among humans may be an indirect legacy of this adaptation. Like the defects seen in the long-lived *daf-2* worms, minor variations in the genes encoding insulin, its receptor, or other components of its signaling pathways might be advantageous during times of famine, thus gaining a selective advantage. Such variations, however, also underlie some forms of diabetes.

Indeed, even if the long-lived worms don't show the way to vastly extending the human life-span, they offer researchers a new model system in which to study insulin signaling. That, Riddle, Ruvkun, and other researchers point out, may improve biologists' chances of designing treatments for diabetes, the seventh leading cause of death in the United States. "Not everything we find will be directly applicable," says Jazwinski, "but now that we're generating findings more and more quickly, the odds are in our favor."

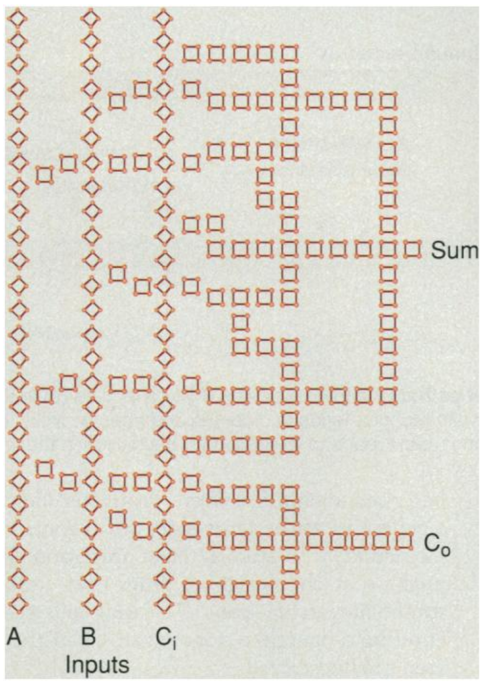
–Wade Roush

TECHNOLOGY

Quantum Cells Make a Bid To Outshrink Transistors

Electrical engineers are heading straight for a bruising encounter with the laws of physics as they continue to shrink transistors. Even the most gung-ho circuit builders know that heat overload and quantum effects, such as the elusive behavior of electrons on very small scales, will eventually stop them from packing more and more transistors onto a single computer chip. But 6 years ago, a pair of electrical engineers, Craig Lent and Wolfgang Porod at the University of Notre Dame in Indiana proposed a scheme for dodging those limits—even exploiting them.

They realized that when transistor sizes bottom out, the quantum fuzziness of very small scales might actually be the key to shrinking electronics still further. They proposed that dominolike arrays of "quantum dots," in which electrons would quantum-mechanically "tunnel" from dot to dot, might one day outshrink transistors. The notion met with incredulity in the electrical engineering world, where more conventional schemes relying on quantum dots have yet to demonstrate their practicality (*Science*, 17 January, p. 303). A paper on page 928 of this issue shows, however, that Lent and Porod's quantum-dot dominoes—called quantum-dot cellular automata (QCA)—really do work, at least one at a time.



SOURCE: C. LENT AND P. D. TOUGAW

Domino theory. The interactions between many quantum-dot cells, each with four dots, create this adder, designed by Craig Lent and P. Douglas Tougaw.

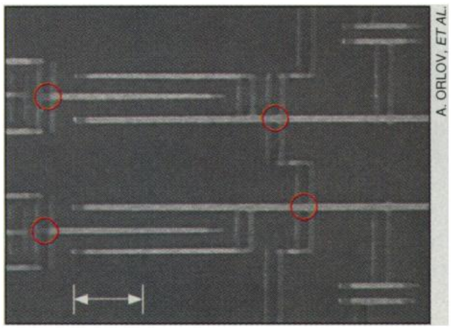
The paper, by Alexei Orlov and several colleagues at Notre Dame—including Lent—describes the first functioning model of a single, four-dot QCA cell. "We showed that this little thing goes click clack," says Lent. Spanning 8 microns, several times the size of today's smallest transistors, and working only when cooled all the way to 15 millikelvin to keep thermal noise from rattling electrons out of their dots, the cell "is just the first baby step" for the technology, says co-author Gary Bernstein.

Some researchers are hanging on to their earlier skepticism, saying that the QCA approach is conceptually flawed and won't work when it is extended to an entire system of cells. But the group's working QCA has impressed others. "This is a key demonstration that the concept could work," says Pierre Petroff, a materials scientist at the University of California, Santa Barbara (UCSB). The remaining hurdles—though daunting—are largely technical, says Terry Fountain, in the department of physics and astronomy at University College London. "The Lent-Porod approach does constitute a new and promising possibility to shrink computer architectures," Fountain says, which could, in principle, reduce circuit areas by factors of as much as 50,000 compared to the smallest feasible transistors.

Existing chips are etched with thousands or millions of transistors, in which electrical currents are switched on and off with electric fields—or, equivalently, voltage biases—in semiconducting materials based on silicon. Conduction channels, or "wires," link the transistors and other components of a chip to create the physical basis of binary logic—the electronic 1s and 0s that are further manipulated in computations. But within the next decade or two, as the size of the smallest circuit features drops from today's 1/3 of a micron to less than 1/10 of a micron, the physical limits facing conventional electronics will assert themselves.

For one thing, the proliferating interconnections will start to wipe out the gains due to smaller sizes. For another, the heat generated by electrical resistance will be harder to dissipate. And finally there is the wavelike, quantum-mechanical nature of particles on tiny scales, a fuzziness that lets electrons tunnel and escape through the walls set up to channel them—the narrower the walls, the easier the tunneling.

In principle, at least, QCA cells do away with all of these problems. Each cell consists of a square arrangement of four quantum dots—minute islands of a material that has a higher affinity for electrons than the surrounding material. Two electrons inhabit each cell. Their mutual repulsion forces them into opposite corners, like boxers between rounds; the two possible configurations stand for binary 0 and 1. The electrons rely on tunneling to move from dot to dot, which they do under the influence of adjacent cells. Like neurons in the retina of the eye, they process information by interacting with their neighbors rather than by sending impulses to some central location, which is why they are called cellular automata.



A. ORLOV, *ET AL.*

Tunnel vision. Electrons tunnel between aluminum islands (indicated by red circles) microns apart in a quantum-dot cell.

When a cell at the end of a row is forced into state 1, for example, the next cell will flip into the same state, since that ensures the maximum distance between electrons in the two cells. The rest of the cells will quickly fall into line, passing the 1 down the "wire." Such wires could be intertwined to perform more complicated operations in which one state can be contingent on several others (see diagram).

Since each signal passes down the line without any current, little heat is generated, and because each cell passes information directly only to nearby cells, which can then send the results to the next cluster for further processing, the interconnection problem is eased. And the smaller the dots are made, the better they confine electrons, keeping thermal fluctuations from dislodging them; indeed, extremely small cells could operate at room temperature. "Things only get better as you shrink them down," says Lent. "It could go down to molecular levels."

But would this theorist's dream fall to pieces in a real experiment? Some critics had predicted that the electrons would leak away through interactions with defects and free charges in the surrounding material, rather than remain stably confined. Others had questioned whether the dots could be made accurately enough for the tunneling to work as designed.

To test the scheme, the Notre Dame group used a tightly focused electron beam to lay out a single QCA—an array of four aluminum dots on a silicon dioxide surface. They put the device through its paces by using voltage biases to force electrons either up or down on one side of the cell (call it the right side) and checking whether the electrons on the left side responded. They found that electrons did move to the opposite corner on the left side, remaining there for periods of minutes. "We can sit there and watch it," says coauthor Greg Snider, "and, no, [the charge] doesn't leak off."

In a complicated set of measurements in which one pair of dots actually probed the other, Snider and co-workers also determined the electrical potential—an indicator of how charges are distributed—on the left pair as the switching took place. The fluctuations in the potential compared favorably with theory, suggesting that electrons really were tunneling between dots and were not, say, being drawn randomly from defects in the crystal lattice. "I think it is a very important breakthrough," says Tamás Roska, a professor at the Computer and Automation Institute in Budapest. "These are not easy experiments," adds UCSB's Petroff. "But I have no doubt [that the switching was observed]."

He notes, however, that QCA's longer term prospects remain controversial because of questions about how well large systems of the dots will function—even if they can be accurately fabricated in much smaller sizes, which would require new techniques. Rolf Landauer of IBM's T. J. Watson Research Center has persistently questioned whether "exactly two" electrons will stay confined in each cell—crucial for such a device to work properly—and whether slight defects in the system will play havoc with its computations. A more vociferous critic, Supriyo Bandyopadhyay of the electrical engineering department at the University of Nebraska, Lincoln, says "fundamental flaws" in the scheme will prevent the arrays from working even if they are built perfectly. For example, the system may get permanently stuck at a wrong answer on its way to the right one, he and his collaborators say, as the electron states reach an impasse akin to traffic gridlock on downtown streets.

Lent says the group has addressed some of these doubts and is studying others. His detailed calculations show, for instance, that running an array at slightly slower than its maximum speed—so-called "adiabatic switching," an approach suggested by Landauer—gets around the wrong-answer problem, just as conservative drivers have a slower commute, but cause fewer traffic snarls than heavier-footed motorists. Still, he says, "One is rightfully concerned about overselling a technology." Whether the click clack of his group's dots will turn out to be first footsteps leading computer science into the realm of the very small remains to be seen.

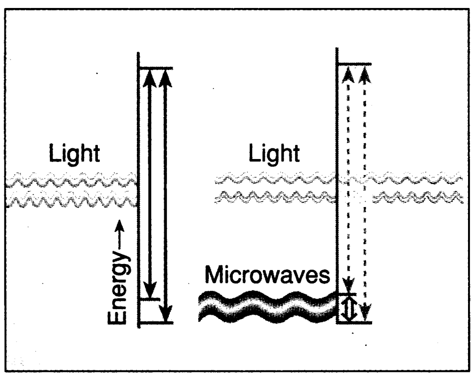
–James Glanz

PHYSICS

Microwaves Steal the Blush From Ruby

Rubies are red, and they usually stay that way. But in the 28 July *Physical Review Letters*, researchers at Wayne State University in Detroit report that they have made rubies a little less red and more transparent with nothing more than a magnet and a bath of microwaves.

The feat, called electromagnetically induced transparency, had already been demonstrated in gases. But "this is the first work in solid-state materials," says electrical engineer Yang Zhao, one of the researchers. He and others say it might eventually lead to more efficient lasers and to optical switches for computers.



LIZ CARROLL

A lock on absorption. Electrons that normally absorb light by jumping to a higher energy level (left) are stymied when microwaves couple two lower levels.

Color, in rubies and most other materials, arises because electrons in the material absorb specific wavelengths of light. The absorption takes place when a photon of light with the right energy kicks an electron from a low-energy level into a higher one. To clear a path through an absorbing material, electrons must be prevented from jumping up to the higher energy level—not an easy task.

Researchers working with gases had already demonstrated a way to shackle these jumping electrons: Use electromagnetic fields to link the lower energy level—the electrons' jumping-off point—with another level at a similar energy. To apply this strategy to rubies, Zhao and his colleagues cooled the material to 2.4 degrees above absolute zero to "sharpen" the energy levels. Then they placed it in a magnetic field, which split each of the energy levels into two closely spaced levels through what is