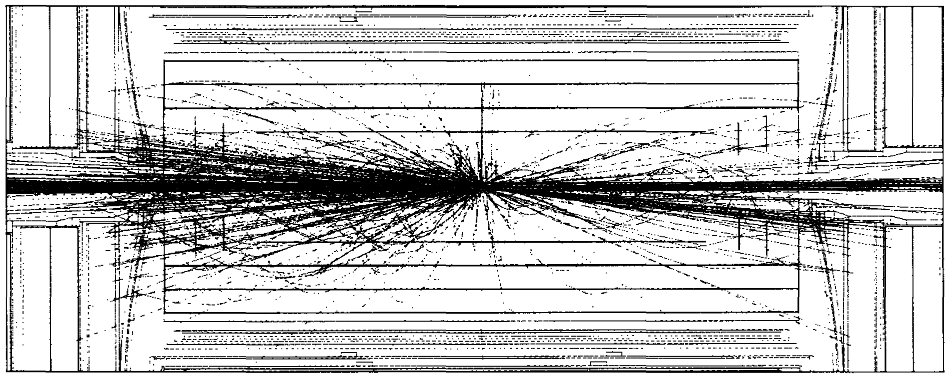
between 105,000 and 125,000 years ago—well before the earliest dates on other continents. "Those dates make great sense to me," says Klein. "They are entirely consistent with other lines of evidence," such as signs of climate change in the geologic record. The dates also dovetail nicely with results from another South African site, Border Cave, reported by University of Colorado geochemist Gifford Miller, who worked on racemization in mollusk shells as a postdoctoral researcher in Hare's lab at Carnegie. Miller and his graduate student Beverly Johnson have dated ostrich eggshells associated with a modern human adult and infant to earlier than 105,000 years, although Klein questions whether the human remains are as old as the eggshells associated with them.

Not long afterward, anatomically modern humans appear in the Middle East, and the eggshells suggest they weren't just passing through. By dating shells at Qafzeh cave in Israel, Brooks has found that these humans occupied the caves intermittently for at least 20,000 to 30,000 years. That pleases Harvard University archaeologist Ofer Bar-Yosef, who had already observed that the layers of sediment associated with humans at the site must have built up slowly. And although this site has no good specimen for calibrating the eggshell dates with radiocarbon, thermoluminescence and electron-spin resonance methods have suggested that the occupation was under way 90,000 years ago.

The ostrich eggshells are also giving the anthropologists a better picture of what human populations were doing in those early days. At another site in South Africa called Boomplaas, the dating has confirmed that unusually sophisticated tools—known as the Howieson's Poort industry—were made as early as 80,000 years ago. And about the same time, or a little later, early humans were using the same technology at Klasies River Mouth and at Border Cave. "We're beginning to see more advanced technology and more advanced work in bone and shell at earlier dates," remarks Brooks. It wasn't long before the eggshells themselves became part of that technology, in the form of ostrich-eggshell jewelry. At the Mumba shelter in Tanzania, Brooks has dated a level that yielded flat ostrich eggshell beads with holes in the center to between 40,000 and 50,000 years ago.

All of which might be enough to make anthropologists working in ostrich-free zones feel they are missing out. But Brooks and Hare are holding out hope for researchers in other regions. Their team and Miller's are studying eggshells from other birds, such as owls, cranes, and emu, and so far those shells appear to be equally good timekeepers. Says Brooks: "Apparently, an eggshell is an eggshell, however thin and fragile it may appear."

–**Ann Gibbons**



SSC LABORATORY

Find the Higgs. In this simulated tangle of tracks, it will take smart electronics to spot the particle.

HIGH-ENERGY PHYSICS

Neural Nets: A New Way to Catch Elusive Particles?

Any day now, Germany's latest high-energy accelerator, HERA, will start drowning its creators in data. Located at the DESY laboratory near Hamburg, this machine will collide electrons and protons 10 million times a second. Each collision will spray bursts of other particles into HERA's two detectors, which will turn it all into electronic blips—10 megabytes of them every second. That's enough data to stretch to the limit the electronic analyzers sifting the information in search of the one-in-a-trillion event that might signal a new discovery, says HERA scientist Bill Haynes. And yet it's only a trickle compared to the torrent of data predicted for the next generation of accelerators: CERN's Large Hadron Collider (LHC) and the United States' Superconducting Super Collider (SSC).

Anticipating the onslaught, physicists are turning HERA and other accelerators into testbeds for a computer technology known as the neural network: a web of simple processors, interconnected rather like the neurons in a brain, that can be "trained" to spot novel events in a morass of background data. For now, HERA and the other high-energy accelerators rely on ordinary switches and computer algorithms that pick out interesting events according to preset criteria. But in tests over the next few years, scientists will take signals collected by detectors at HERA and other accelerators and feed them into neural networks to see how efficiently they can learn to recognize the signatures of exotic particles. If the results are promising, neural networks might serve as the basis for a new generation of faster, more flexible detector electronics—just the thing, advocates hope, to snare a Higgs particle or a Top quark.

The most difficult and important job in particle detectors, says Roger Barlow, a physicist at the University of Manchester in England, is recognizing the difference between interesting and boring events. And in an accelerator, he points out, "there are 10^9 times as many boring ones as interesting." That's where the powerful pattern-recognition ability of neural networks comes in, the physicists say. The signature of a rare particle or event often consists of thousands of secondary particles flung out in all directions from the point of impact. The "connectedness" of a neural network, says Barlow, should enable it to gather data from all parts of the detector and "tie it all together to make a global decision."

What's more, neural networks, unlike conventional computers, can learn to make distinctions their creators couldn't anticipate. With a neural network you don't have to figure out how to recognize a pattern yourself and then wire up hardware or program software to do it, says Barlow. Instead, you "train" the neural network to recognize the pattern, without giving it a formula. The "training" is a little like teaching a person to recognize a letter or pattern, he says. "You show the network a set we know is [one kind of] quark, and ones we know are not, and adjust it until it knows which is which." The network adapts to the task on its own, changing various weighting factors that influence the relationship between input and output. The human user doesn't need to know the functions or formulas the network invents to make distinctions, says Caltech physicist Thomas Gottschalk. "If I'm willing to take forever to train it, the network has the flexibility to find whatever the best function is even if I don't have a clue."

To put that promise to the test, Barlow and other detector physicists are working to incorporate neural networks throughout the data sifting process. At accelerators such as

HERA and Fermilab's Tevatron, the first stage of sifting takes place "on line," as the detector generates data: A set of electronic "triggers" throws out most of the uninteresting background data immediately. The next cuts happen in the subsequent "off line" sorting of the hundreds of collisions per second that the detectors had decided to keep and store.

For the off-line sorting of stored data, Barlow has designed a neural network to distinguish the signature of the exotic, heavy particle known as the bottom quark from those of its four lighter and more commonplace quark relatives. "To tell them apart you have to be clever," says Barlow. You can't spot the quark directly, because quarks never exist alone. A lone quark created in an accelerator immediately explodes into a "jet" of other particles. And the jet generated by the bottom quark looks pretty much like the jet from any other quark, says Barlow. But he thinks a neural network could reliably spot the subtle differences.

Fermilab physicist Bruce Denby has chosen a comparable challenge for his off-line networks: distinguishing quark jets from those created by the particles known as gluons—the "force" particles that bind quarks together into protons and neutrons. If the networks succeed in making the distinction reliably, he says, his Fermilab colleagues may put them to work sorting stored data for the signature of the long-sought top quark. The top, says Denby, should leave its mark in the form of six jets, some from other secondary quarks and some from gluons. The proportions of quark and gluon jets are what distinguish that pattern from the background events, 1000 times more numerous, that produce similar jets. But that's a distinction that might elude conventional electronics, says Denby.

As for the more difficult goal of harnessing neural networks to make decisions "on line," right as the data come streaming out of the detector, Denby says he and another research group headed by physicist Paul Ribarics of the Max Planck Institute are getting close. Denby's on-line neural net will operate at Fermilab's Tevatron, while Ribarics' will work on the soon-to-be running H1 detector at Germany's HERA. Both networks may help the conventional detector electronics filter out distracting background events, but the main purpose of the tests is to learn more about the performance of neural networks, says Denby. "My philosophy is to get something simple working and learn about it and then see about SSC and LHC," he says.

HERA's Bill Haynes agrees that the tests are worth doing. But he notes that neural networks have yet to prove themselves. "We haven't seen a real application which can't be done with conventional technology," he says. "I'm looking forward to seeing what they can do on H1."

Other observers are openly skeptical, admits Denby. "Some people will tell you it's all crap." But if the first round of tests pan out, there will be every incentive for skeptical physicists to take a second look at neural nets. The data overload, after all, is on everyone's mind—including that of CERN general director Carlo Rubbia, who at an LHC detector meeting last March bemoaned the "mismatch between the efforts of the machine and the leisurely pace of the detector," which he feared won't work fast enough to find all the valuable events. To redress the imbalance, says Haynes, "we'll need all the techniques we can get."

–Faye Flam

CHAOS

Putting Gentle Reins on Unruly Systems

Chaotic systems, including hearts gone berserk, turbulent fluids, and the weather, have a way of driving researchers into agonies of frustration. But those trying to control chaotic systems had better restrain themselves. As a group led by physicist Troy Shinbrot reports in the 11 May *Physical Review Letters* (*PRL*), such systems respond best to a gentle hand. In the latest stride toward taming chaos, Shinbrot and his colleagues at the University of Maryland, together with workers just up the road at the Naval Surface Warfare Center (NSWC), have succeeded in subtly nudging a chaotic system toward a chosen behavior. And that brings visions of quieting arrhythmic hearts, streamlining turbulent flows over moving vehicles, and improving yields in chemical reactions a step closer to realization.

At the center of Shinbrot and company's chaotic system is an upright ribbon of a magnetoelastic material—one whose stiffness depends nonlinearly on an applied magnetic field. As the field oscillates, the ribbon alternately straightens and buckles. Gravity's downward tugs add spice to the motion, turning it into a chaotic jig. Controlling that unruly dance means capturing just one of its moves, says Mark Spano of NSWC. "The chaotic motion is a jumble of an infinite number of periodic motions," Spano says, "but you want just one."

Spano and his NSWC colleagues Steven Rauseo and William Ditto reported the first hint of success in the 24 December 1990 *PRL*. Using a method proposed earlier in 1990 by Shinbrot's University of Maryland colleagues Edward Ott, Celso Grebogi, and James Yorke, Spano's team was able to constrain the ribbon's chaotic motion near a selected periodic motion by subtly adjusting the magnetic field (*Science*, 10 May 1991, p. 776). Seals balancing balls on their snouts do the same sort of repetitive adjusting. But the strategy had a major drawback: The researchers had to wait, and wait some more, until the chaotic ribbon happened to move, or orbit, roughly the way they wanted it to. Only then could they adjust the magnetic field to capture the target orbit. For potential applications such as controlling chemical reactions or mechanical vibrations, that waiting period could be a fatal flaw.

But another paper in the same issue of *PRL* offered the beginnings of a solution. In it, Shinbrot, Ott, Grebogi, and Yorke argued on the basis of theory and computer simulation that chaotic systems in an arbitrary initial state can be steered with gentle but judicious nudges to a desired target state. That would free chaos tamers from first having to wait until their system wandered into the kind of behavior they wanted.

Now the Maryland quartet, Spano, and Ditto (now at the College of Wooster in Ohio) report "the first experimental confirmation" of this possibility. Their success rests on the fact that, in a chaotic system, a little nudge goes a long way; as chaos lore has it, a butterfly fluttering in India can cause a hurricane in the Caribbean. To steer the magnetoelastic ribbon into one kind of periodic motion, the group first systematically mapped out how small changes in the magnetic field affected the ribbon's motion. The map then guided the researchers as they adjusted the field to steer the ribbon into a target orbit.

The added control enabled Shinbrot and his colleagues to direct the ribbon's chaotic jig in seconds; in 1990, it took the NSWC team days to accomplish this feat. "It's an important advance because it greatly decreases the time you have to wait before getting a desired state," says Rajarshi Roy of the Georgia Institute of Technology, who works on controlling chaotically fluctuating lasers. With such control, researchers could turn the sensitivity of chaotic systems to advantage, Shinbrot says. Changing the behavior of a stable, nonchaotic system such as a simple pendulum often takes a powerful jolt of energy. With a chaotic system, in contrast, "you use the system's sensitivity to initial conditions to get you where you want to be," says Ditto. As a result, points out Ott, "you can do a lot in the way of control, even though you may be limited in how you can turn the knob."

For chemical engineers trying to toggle between two possible products of a given reaction or aerospace engineers aiming to change a satellite's orbit dramatically using the least amount of fuel, this new control over chaos may well expand their sense of what is possible.

–Ivan Amato