have been no models for neural processing showing oscillating activity." While the work seems unconnected with Sanyo's bread-and-butter electronics business, the goal of Sekiguchi's 12-person biosystems group is one day to develop a model of biological information processing that could be used to build computers.

And finally, let's come back to NTT's Kawana. His measurements of the electrical communication that goes on within small networks of neurons seem to reveal the rudiments of organized behavior among the neurons. "The entire network, about every 10 seconds, fires and then is silent," he says. Understanding the spontaneous and coordinated firing of the networks of neurons is now the focus of his lab's research. At this early stage of the research, no final answers have yet emerged, and it's still too early to tell whether the information will help in computer design.

Indeed, the same can be said of the other industrial lab-based neuroscience programs, raising a question about just how promising they are. One answer might come from the fact that none of these private labs has yet surpassed the best research being done elsewhere in the world.

Given the long road that will have to be traveled before the companies see any fruits of their basic neuroscience research, there's also the question of how long the companies will continue to fund the research, especially considering the fact that after enjoying a booming economy for much of the 1980s, Japan is now in a recession. But so far, at least, bioscience researchers say that they have not experienced cutbacks, although some feel pressure. "Bio-research is expected to have a great impact on Sanyo's future business, so it seems very important to continue small-scale research despite the severe economic conditions," says Shigeru Mackawa, the head of Sanyo's Tsukuba Research Center.

If Japan's corporate neuroscientists can persevere, theoretical neuroscientist Christof Koch of the California Institute of Technology is optimistic about their prospects: "Look at Bell Labs. They developed the transistor, they developed the laser. They have a spectacular record. I don't see why it should be different in Japan."

–Toomas Koppel

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PHYSICS

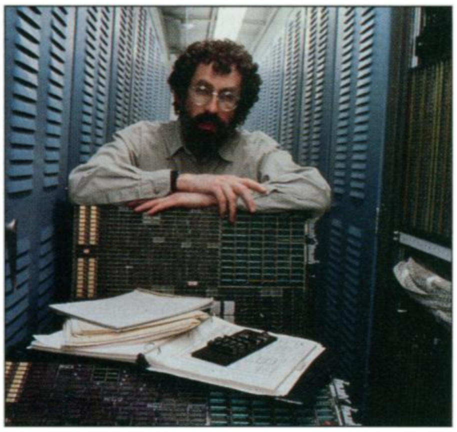
Mass Calculations Add Weight to QCD

Theories of fundamental particles and forces aren't easy to put to the test. Physicists usually do so by whirling protons or electrons at high speeds in particle accelerators, smashing them together, then analyzing the debris for telltale traces that would confirm their ideas. But a group of IBM researchers has now taken another tack to make one of the most stringent tests yet of quantum chromodynamics (QCD), a theory that is a key part of physicists' picture of the subatomic world.

Rather than depending on the energies achieved in a particle accelerator, the researchers, led by physicist Don Weingarten, relied on another kind of brute force: a year of intense calculations in a special-purpose supercomputer. By showing that QCD correctly predicts the masses of the proton, neutron, pion, and others of the fundamental particles called hadrons, the calculations give additional support to QCD, says Daniel Zwanziger, a theoretical physicist at New York University. They also provide an impressive demonstration of what some researchers are calling the "third branch of science"—using superpowerful computers to simulate physical processes with such fidelity that many researchers think of them as more like experiments than theoretical calculations.

QCD is the theory that describes the "strong force," the fundamental force that, among other things, holds together protons and neutrons in the atomic nucleus. The theory posits that protons, neutrons, and other hadrons (the particles that respond to the strong force) are made up of quarks and antiquarks, all held together by gluons. A proton, for instance, consists of three quarks; a pion comprises a quark and an antiquark. Over the past two decades, physicists developing QCD have applied the theory to predicting what happens at extremely high energies such as those achieved in particle accelerators.

But because of the theory's mathematical structure, QCD is much harder to work with at low energies than high. Calculating the rest mass of the proton, for instance, involves not only knowing the masses of the three quarks in the proton but also computing the binding energy of the gluons that hold the quarks together. Because these gluons inter-



IBM

The strong force was with him. Weingarten.

act with each other, the calculations are nonlinear, and it's impossible to reach an analytical solution. As a result, scientists have to approximate a solution through complex numerical calculations aimed at reproducing the behavior of the gluons.

Weingarten has worked for more than a decade cooking up algorithms to do just that. His approach, called lattice QCD, makes the calculations more tractable by breaking up continuous space-time into a finite four-dimensional lattice of points. To home in on a solution, though, Weingarten had to expand the lattice and shrink its spacing, which increases the number of lattice points that must be considered and makes the number of computations mushroom. As a result, Weingarten has devoted much of his effort to finding ways of streamlining these calculations.

At the same time, Weingarten was also developing a computer that was up to the task. In 1982, he left a tenured position at Indiana University to join IBM's Thomas J. Watson Research Center in Yorktown Heights, New York, where he and other IBM workers designed and built the GF-11, a massively parallel computer with 566 processors intended specifically for QCD calculations. Then, with Frank Butler, Hong Chen, Jim Sexton, and Alessandro Vaccarino, he set it loose on calculating the masses of hadrons—a task that eventually took a year and more than one hundred quadrillion (10^{17}) arithmetic operations.

As reported in last week's issue of *Physical Review Letters*, Weingarten's team computed ratios among the masses of 11 hadrons, including the proton, pion, kaon, delta, omega, and other members of a Greek alphabet soup. Because the QCD formulation includes three unspecified parameters (the quark charge and the masses of the normal and strange quarks), Weingarten fixed three of the hadron masses according to experimental measurements, which left him with predictions for the masses of the eight remaining hadrons. All agreed with experiment to within 6%, and most were a good deal closer.

Besides vindicating the theory, Weingarten says, the calculations demonstrate just how important the computer has become in theoretical physics. Other theories of the subatomic world can be solved analytically. But for exploring the predictions of QCD, says Weingarten, computer simulation—what he calls "experimental theoretical physics"—has become an essential implement in the physicist's toolbox.

–Robert Pool