by John Donoghue at Brown University and Schwartz at the Neurosciences Institute in La Jolla are experimenting with multiple electrodes placed in the motor cortex of monkeys. And at the neuroscience meeting this week, Richard Andersen's group at the California Institute of Technology in Pasadena described similar experiments in the parietal cortex, which helps transform sensory information into plans for movements.

Brain bug. Several teams use this 25-electrode array (4.2 mm^2), seen next to a dime, to record neural signals from a monkey's cerebral cortex.

They all share the same goal: to use neural firing information recorded in real time to reconstruct the motions of the monkeys' arms. If the scientists can interpret the direction, speed, and distance of arm movement from the corresponding neural signals, then they should be able to use the nerve-firing pattern to direct the movements of a mechanical arm.

The hope is to "generate natural-looking arm movements, like reaching toward a glass, or gesturing," says Schwartz. Toward that goal, Matt Fellows and Liam Paninsky from Donoghue's team also reported at the meeting that they have recorded neuron firing in the motor cortex as a monkey used its hand to follow a randomly wandering cursor across a screen. From the firing patterns, the researchers derived a mathematical code that could reconstruct the path of arbitrary arm movements the monkey made later.

That all these variables could be predicted "based on the information you can get out of fewer than a couple of dozen cells," Donoghue says, "means the potential for recreating the entirety of any movement is much better than I would have expected." His team has already used neural information recorded from a monkey to direct the movement of a prosthetic arm to one of eight points in space, and it plans to go on to more natural, less constrained movements.

Schwartz and his collaborators at Arizona State have just achieved that goal. At a neural prosthesis workshop at the National Institutes of Health 2 weeks ago, Schwartz reported that they have operated a robotic arm directly from recordings of 26 neurons in a monkey's brain, mirroring the animal's own arm as it pushed buttons on a panel or chased an almond across a tabletop. The neural activity provided velocity and direction of movement, which the researchers fed every 20 milliseconds into the computer controlling the robot. The computer determined which joints to move, and how much. The result, says Schwartz, is "three-dimensional, natural arm movement through free space."

In these experiments, the monkeys went about their business unaware of the robotic arm. The next step will be to have the animals consciously controlling the arm, much as a paralyzed person might.

The eventual performance of these devices in people will be aided, researchers expect, by the brain's well-proven plasticity in adapting to new tasks. That plasticity suggests that implantable prostheses need to be placed only in the general vicinity of the correct brain region—such as the motor cortex—rather than linked up to the very neurons devoted to particular movements, a correspondence that may be impossible to achieve in paralyzed patients. Then the brain should take over, learning to run the prosthesis with whatever neurons have been linked to it, much as neighboring brain areas assume new tasks after a stroke.

Another hurdle to surmount is how to incorporate sensory feedback, such as pressure from touching an object, into a prosthesis. However, robotics research has shown that people get "an amazing amount" of useful feedback solely from what they are seeing, says Schwartz, who believes this will not be difficult to overcome. A stickier problem, he says, will be getting enough neural information to control fine hand motions. But even movements crude enough to grasp a spoon could make a big difference in a paralyzed patient's life. "If they could feed themselves, that would be huge," Schwartz says.

Scientists are optimistic that the engineering will carry the day, now that neuroscience has shown that the brain has the potential to control prostheses directly. If so, these scientific advances could soon be transformed into improvements in the lives of paralysis victims. "In principle, it should all be possible," says neuroscientist Eberhard Fetz of the University of Washington, Seattle. "The question is to what degree it will become practical." But with the new surge in interest and funding, Chapin predicts that goals "that looked like they might be 15 to 20 years off will suddenly be 5 to 10 years off."

–MARCIA BARINAGA

ARCHAEOLOGY

A Long Season Puts Çatalhöyük in Context

A marathon dig at one of the world's most famous Neolithic villages links it to other, older Near Eastern settlements

ÇATALHÖYÜK, TURKEY—Archaeologist Mirjana Stevanovic is still wondering about the skulls. Last summer, while excavating at this 9500-year-old Neolithic village near the modern city of Konya, Stevanovic and colleagues from the University of California (UC), Berkeley, found two skulls—with no skeletons attached—in a large house. One was that of a boy about 12 years old; the other belonged to a woman in her late 20s. They had been placed on the floor with their foreheads touching. The skulls were discovered very near the spot where, in 1998, the team found evidence that the roof had collapsed.

Did the woman and boy die in the cave-in? Were they mother and child? Both skulls have unusual suture patterns in their bones, possibly lending support to the notion that they were related, says Başak Boz, an independent anthropologist from Ankara who is working with the team. And other clues at the site suggest that family ties were very important to these villagers.

But no one can say for sure why the skulls were placed together. "All I know," says Stevanovic, "is that they were put that way deliberately."

The skulls are just one more puzzle at Çatalhöyük, the largest Neolithic community yet discovered, which offers a rare glimpse of early settled life. But, although the secret of the skulls may never be revealed, the international team that has been excavating here for the past 6 years is beginning to decipher other mysteries of this ancient settlement. A

Neolithic neighbors. Çatalhöyük is now seen as part of the same cultural tradition as other ancient Near East villages.

CREDIT: (TOP) K. SHENOY

marathon, half-year digging season that ended earlier this month yielded new dates, suggesting that Çatalhöyük is not quite as old as the 10,000 years archaeologists had estimated—and certainly not the "first city" it has sometimes been called. This revised chronology, together with other clues, links the settlement with the cultural tradition of others of the time in the Near East, says excavation director Ian Hodder of Stanford University. But Çatalhöyük remains unique, with up to 10,000 inhabitants crowded together for reasons that remain murky. "Çatalhöyük pushed the idea of a village to its logical absurdity," Hodder says.

First excavated in the early 1960s by the British archaeologist James Mellaart, Çatalhöyük was once thought to be a textbook case of an advanced agricultural settlement. Its people lived in mud-brick houses packed so closely together that they had to enter through holes in the roofs. They painted vivid hunting scenes on their plaster walls, buried their dead under the floors, and during at least 1000 years of occupation rebuilt houses one on top of another, creating a mound 20 meters high.

Many of those startling finds still stand. But when a new group of archaeologists, led by Hodder, started excavating here again in the early 1990s, it began rewriting the Çatalhöyük textbook. These researchers found only rudimentary agriculture and little evidence of what Mellaart claimed was worship of a Mother Goddess (*Science*, 20 November 1998, p. 1442).

This year's long dig, the equivalent of three or four normal seasons, was originally prompted by a falling water table—caused by intense crop irrigation nearby—that was threatening to dry out the fragile mud-brick structures. But the lengthy fieldwork was also an opportunity to do a lot of excavating, and its fruits are allowing Hodder's team to rewrite the text once again. The team deepened and broadened an area on the south edge of the mound that Mellaart had dug earlier, and it continued excavations in a separate building on the north side, where the skulls were found. The archaeologists had thought that several meters of remains might lie beneath the lowest levels reached by Mellaart, representing as much as 1000 years of even earlier occupation. But long before the end of the season, they hit clay marl. They realized that in the deepest areas Mellaart reached, he had been only 20 centimeters above virgin soil.

Although earlier occupation levels might still lie below the center of the mound, this unexpected finding, combined with new radiocarbon dates putting Mellaart's lowest levels at about 7500 B.C., suggests that the earliest settlement at Çatalhöyük is later than that of a number of other Neolithic settlements in the Near East. For example, Jericho, about 700 kilometers away in Palestine, is at least 1000 years older. That puts Çatalhöyük "fairly late in the overall Near Eastern sequence," Hodder says.

A younger age helps make sense of another of this season's surprising discoveries: At the lowest levels in the Mellaart area, excavators found chunks of burnt lime, a substance common at many Neolithic sites in the Near East, including Jericho and 'Ain Ghazal in Jordan. That's because the plaster used in the mud-brick walls and floors characteristic of these sites was made from limestone, which was heated to at least 750°C and then mixed with water.

Final touch. The skulls of a woman (right) and boy were placed touching each other on the floor of a Çatalhöyük house.

CREDIT: M. A. LÓPEZ

Çatalhöyük's younger age might explain why all of the plaster found so far on walls and floors has been based on clay, which is less durable than lime, and why the loose bits of burnt lime were found only in the earliest levels. Hodder and other members of the team, including micromorphologist Wendy Matthews of the British Institute of Archaeology in Ankara, suspect that lime plaster was used during the settlement's very first days but later given up because its manufacture required too much fuel. Indeed, some archaeologists have speculated that the fairly rapid decline of 'Ain Ghazal and other settlements in the Levant about 8000 years ago might be partly due to the ravages their populations inflicted on the local environment in search of wood to burn.

The burnt lime at Çatalhöyük suggests that the village was influenced by cultural traditions first developed to the south and east, even if the people later switched building techniques. "People came here with a long history," says Christine Hastorf, an archaeobotanist at UC Berkeley.

Even so, Hodder thinks that the community was not settled by migrants but was founded by a small indigenous population, then slowly grew in size. That view is supported by new evidence that the first Çatalhöyük settlers built more dispersed houses; only later, as the settlement became larger, did the honeycombed housing pattern made famous by archaeology textbooks emerge.

With this year's marathon digging season at an end, the team plans to limit excavations over the next 2 years so it can study the new finds. They are hoping to find clues to many unanswered questions, chief among them why Çatalhöyük grew so large, and why the villagers lived so closely together rather than spreading out over time. Other Neolithic sites are also mounds or tells, as people constructed new buildings over the remains of old ones, but Çatalhöyük's tightly packed, layered houses are an extreme example. There's no evidence of warfare, and Hodder doesn't think this arrangement was for defense. Instead, he speculates that family ties spanning generations held the community together: People built their houses over the patch of land claimed by their ancestors.

The touching skulls—as well as elaborate child burials found this year, such as infants packed into finely woven baskets—may offer additional signs of the affection Çatalhöyük parents felt for their children. But the high child mortality rate indicates that life for Çatalhöyük's younger members was hard. The eye-socket bones of most children found here are unusually porous—a sign of anemia and likely due to malnutrition, says Boz. Hodder speculates that child labor might have been essential for keeping the community viable: "Childhood as we understand it today probably was not relevant back then."

Although this year's excavation season seems to have taken Çatalhöyük out of the firmament of archaeological stardom and placed it more squarely on Near Eastern soil, Çatalhöyük's extraordinary paintings and artifacts do not fit perfectly into any existing Neolithic tradition. And, unlike other large villages and towns in the Near East, which began to show signs of centralization and hierarchy once they grew to a certain size, Hodder says that Çatalhöyük shows no evidence of public buildings or division of labor and seems to have lived on as an "egalitarian village," despite its dramatic growth. "It is part of a broader trend, and yet remains unique. That is what's so extraordinary about it."

–MICHAEL BALTER