most of the photons that were produced were simply reabsorbed rather than emitted.

But a trickle of experiments continued to hold out hope, says Friend. For one, in 1992, UCSB physicist Daniel Moses showed that semiconducting polymers in a dilute solution could be coerced to emit laser light. And over the next few years, several groups demonstrated that thin films of common semiconducting polymers did indeed show high luminescence efficiency when blasted by laser light. "Once you get a high luminescence-efficiency material, it ought to lase," says Friend.

Only the reabsorption of photons was preventing true lasing in the polymers, it seemed. Impurities or defects in the films appeared to be at fault, says Heeger, so in this round all three groups were careful to limit such impurities.

That care seems to have paid off, and in late July all three groups presented evidence of success at a conference in Snowbird, Utah. Each team fired strong beams of laser light at their polymer films and were rewarded by light emerging from the polymers at a specific wavelength. While the Cambridge and Utah groups each showed this effect for a single polymeric material, the California group demonstrated the phenomenon in more than a dozen different semiconducting polymers or polymer blends. Each material gave off a different wavelength of light, showing that in principle at least, polymer lasers can cover much of the visible spectrum, including yellow and blue—colors with which conventional diode lasers have trouble (see figure).

The ability to emit light at just one wavelength, however, is just one criterion of a true laser. The waves also have to travel in step, and this "coherent" light has to form a single beam. At this point, none of the three groups has quite met all these goals. But the Cambridge group, which published their results in the 22 August issue of *Nature*, has demonstrated all but coherence, and at this point that is likely just a formality, says Heeger. Friend and his co-workers went the extra step by placing their polymer film inside a tiny device known as a microcavity, which contains a pair of mirrors that bounce the photons back and forth through the lasing material, coaxing the material to emit more and more photons in the same phase and shaping the emitted photons into a directed beam. Placing the other polymers in similar devices should yield similarly improved performance, says Heeger.

Although that's likely to be an easy step, most laser experts agree that the real goal of making electrically powered polymer lasers is further away. One big problem is the amount of energy needed to kindle current plastic light-emitters. To match the intense laser light now used to deliver that energy, electrically powered devices would have to shoot thousands of amperes of current into the thin polymer films in a fraction of a second. That task, says Garnier, "would be absolutely incompatible with current electrode designs."

And thanks to quirks of quantum mechanics, semiconducting polymers are far more likely to emit light when pumped with photons of light rather than with electrical charges, notes Utah's Vardeny. When electrically pumped, at least three-quarters of the charges end up generating not light but heat, which may cause the device to burn out quickly.

Can semiconducting polymers meet all these challenges to make commercially viable plastic lasers? Given these latest results, "it's definitely possible," says Garnier. But, he adds, it will require new materials that convert electrical charges to light more easily and can withstand high temperatures. Until such materials are developed, practical polymer lasers are likely to remain a bright light on a distant horizon.

–Robert F. Service

NEUROBIOLOGY

How the Songbird Makes His Song

In human organizations, those at the top tend to set strategy while leaving the details to their underlings. The same thing seems to happen in the brain—at least in the brain of the male zebra finch as it controls the bird's singing. On page 1871, Albert Yu and Daniel Margoliash of the University of Chicago provide the most detailed look yet at how the finch's brain controls the bird's singing muscles, and they find a chain of command that might be familiar to any management-school graduate.

The work shows, Margoliash says, that the singing instructions are relayed down a hierarchy of brain regions, getting progressively more detailed as they go. The firing patterns of the neurons in the higher brain centers apparently specify the more complex components of the birds' songs, the syllables, which are collections of notes, while the patterns at the lower level in this neural chain of command define the basic sounds—most likely, the notes themselves.

While neuroscientists have long suspected that the brain has such hierarchical motor programs, there was little direct evidence for the hierarchy. This report "is something that people have been looking for," comments neuroscientist Eric Vu of the Barrow Neurological Institute in Phoenix, whose own earlier work on zebra finches had hinted at a similar result. "It shows that to perform more complex behavior, the brain follows a chain of command: Higher brain centers are responsible for more abstract [information], and lower brain centers fill out the details." As they traced this hierarchy, Yu and Margoliash also found additional support for the idea that the timing of the impulses from a nerve cell, not just the number of pulses in a given period of time, carries information (*Science*, 3 November 1995, p. 756).

BENJAMIN C. YU

Singing for science. Lightweight headgear, including implanted electrodes, doesn't stop his song.

The findings may also help neuroscientists understand speech production in humans, because human speech, like bird song, is modular. Whereas a song consists of notes strung together in syllables and then phrases, human speech consists of phonemes, basic utterances such as the sounds associated with particular letters, linked together in words, which then form sentences and paragraphs. If the firing patterns of neurons in different brain regions define the finch's notes and syllables, then some similar organization may be at work in the human brain's speech production centers, Margoliash and others suggest.

Until now, the most direct evidence suggesting hierarchical control of bird song came from work done in 1994 by Vu's team. At the time, other researchers had already implicated several regions in controlling bird song. Vu, and subsequently Margoliash and Yu, studied two of them: the HVc, a cluster of nerve cells sometimes called the song production center, and the robustus archistriatalis, which relays input from the HVc down toward the base of the brain, where the RA's nerve cells interface with those that activate the right muscles for making sounds.

For his study, Vu implanted tiny electrodes in either the HVc or the RA of various zebra finches and observed how sending an electrical pulse down the electrode while the bird was singing disrupted the song. Pulses to the RA just caused the birds to make a small mistake—perhaps dropping a note. But a pulse to the HVc stopped their singing altogether for a moment, and the birds would start that part of the song over again.

As a result, Vu concluded that the HVc contributed at a higher level, perhaps by defining syllables or sequences of syllables, while the RA conveyed instructions about the notes needed to create syllables. But to actually prove that, neuroscientists needed to see the actual firing patterns of the neurons controlling bird song. And that is what Margoliash and Yu have provided in their current work.

For their experiments, Yu and Margoliash first outfitted 13 male birds with brain electrodes, projecting into either the HVc or the RA. These electrodes were in turn connected to a computer that recorded and analyzed the electrical impulses from individual neurons in the two brain centers as the birds sang. Because Margoliash also kept track of what sounds the birds made as various cells fired, the researchers could compare the activity of these different cells at the same point in the bird's song, which it repeats over and over again.

These comparisons showed, Margoliash says, that each HVc cell measured had a signature firing pattern that differed from cell to cell but corresponded to a specific syllable. These patterns weren't apparent at first, however, because of what Margoliash calls their "sloppiness." The firing patterns were variable both in the number of bursts in a series and the time between each series. But by lining these patterns up with the corresponding sound recordings, Yu and Margoliash found that the patterns did have subtle similarities, with some characteristic pauses and a recognizable, although not identical, series of bursts for each syllable. Eventually the researchers were able to predict the syllable to be sung just by looking at these patterns.

In the RA, in contrast, the firing patterns were much easier to discern, because the timing of firing varied very little from one round of singing to the next. And in this region of the brain, the patterns seem to correspond generally to individual notes rather than syllables. "As you get closer to the muscles, [the brain] is breaking [the message] down into smaller and smaller units," explains Allison Doupe, a neurobiologist at the University of California, San Francisco. "The precision of the timing [in nerve cells] gets more and more exact." Thus by the time the signal to sing reaches the muscles, that signal has been broken into very specific commands that synchronize each muscle contraction.

Yu and Margoliash have also shown, as Doupe puts it, that there is information not only in neuroscientists' traditional focus, "the neuron turning on and off, but also in the timing of when it goes on and off." In a given RA nerve cell, for example, the researchers found that two bursts of activity with almost no pause in between seem to lead to a different note than, say, three bursts with a slight pause after the first, or two bursts with a long pause between them.

And because Yu and Margoliash could look at the individual activity of several nerve cells at the same point in the generation of the song, they could also see how the combined temporal patterns of groups of cells can have specific meaning to the cells receiving this input. Somehow, the input from several HVc cells, with each firing according to its syllable-specific pattern, sums together to communicate to the RA cells what notes need to be generated for that particular syllable. "It's clear that the brain is a temporal pattern processor," says Margoliash.

Just accomplishing these kinds of measurements in birds was "quite a significant feat," says Doupe. Male finches sing only when they are at ease, and any recording system has to cope with their tendency to puff up their chests and hop about when they sing. Indeed, Margoliash says, he and Yu struggled for a long time to design a workable technique. "We had years where we got virtually no data," Margoliash recalls, until they finally designed a light and robust recording device.

The work should aid more than just future zebra finch studies, because it has possible implications for how the human brain controls speech. Indeed, neuroscientist John Middlebrooks of the University of Michigan, Ann Arbor, suggests that its implications may be even wider. He points, for example, to an intriguing tie between Yu and Margoliash's findings and his own studies of how the ear responds to sounds. Middlebrooks has found that when nerve endings in the ear are stimulated they send a very precise signal to the brain, much like the precise signal the RA sends to the throat muscles in a singing finch. Then as the sound's message travels to ever higher brain centers, it becomes ever more abstract, he notes—Yu and Margoliash's hierarchy in a new setting.

Moreover, Middlebrooks suggests that the way the brain executes the series of movements necessary to make sounds may prove to be the way the brain controls many of the body's activities. "[The findings] will have relevance to many aspects of human behavior," he predicts. If so, then the song of the zebra finch will indeed be music to the ears of neuroscientists.

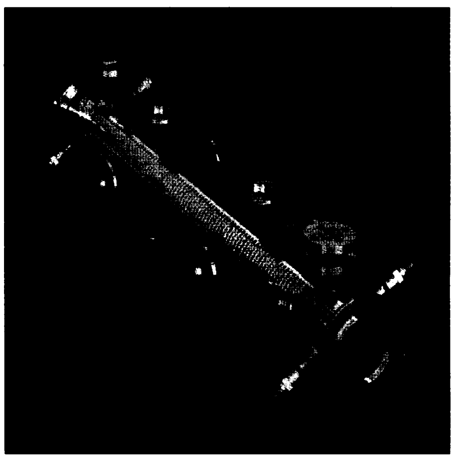
–Elizabeth Pennisi

PARTICLE PHYSICS

Politics Meets Technology in Next Collider

While the morale of the high-energy physicists, particularly in the United States, was severely dented by the cancellation of the U.S. Superconducting Super Collider (SSC) project in 1993, they did not dwell on that setback for long. Soon researchers were cooking up plans for an entirely new and truly international venture: the world's longest linear accelerator, or linac, which could stretch over a distance of 30 kilometers. And late last month, at the 18th International Linac Conference in Geneva, the giant linac took another step from pipe dream to reality, as five different physics groups unfurled blueprints for the machine.

This Next Linear Collider (NLC), as it's called, would not be the most powerful accelerator in the world; that honor will go to the Large Hadron Collider (LHC), soon to begin construction at CERN, the European particle physics laboratory near Geneva. But the unique properties of linear colliders should ensure new physics results to complement the findings from the LHC. The NLC also presents some unique technical challenges. And because the multibillion-dollar machine would be built as an international project at a site yet to be determined, the technical choices are bound up with political ones. "The goal is to look at these designs, and then to make some very difficult choices," says Tor Raubenheimer of the Stanford Linear Accelerator Center (SLAC) in California. "It will take about another year and a half to develop an actual proposal with actual monetary figures," adds



CERN

Fast track. Prototype high-frequency accelerating cavity at CERN.