scription factors. Using the same reporter system, Kirchhammer showed that mutating or deleting individual binding sites changed the overall function of the modules, evidence that every one of the transcription factors performs a specific regulatory function. Certain sites within each module seemed to serve as key "on" switches, as mutating them disabled the entire module; other sites appeared to amplify the activity produced by the module, or to restrict it to certain regions of the embryo.

These interactions, Olson says, "are likely to provide a general mechanism for understanding cell-specific transcription during development." Moreover, Davidson's findings may also have "important evolutionary implications," says Levine. Because each *cis*-regulatory module seems to work on its own, transposing them from one gene to the next may be a convenient way for nature to generate novel patterns of development. And for biologists, it may generate an understanding of how the solo begun by a fertilized egg swells into a multicellular symphony.

–Wade Roush

Additional Reading

C. V. Kirchhammer and E. H. Davidson, "Spatial and temporal information processing in the sea urchin embryo: Modular and intramodular organization of the *CyIIIa* gene cis-regulatory system," *Development* **122**, 333 (1996).

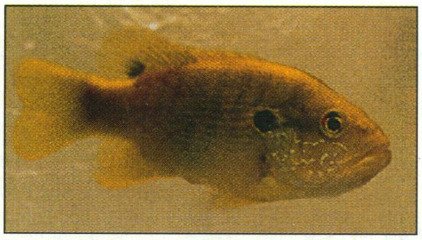
C.-H. Yuh and E. H. Davidson, "Modular *cis*-regulatory organization of *Endo16*, a gut-specific gene of the sea urchin embryo," *Development* **122**, 1069 (1996).

E. H. Davidson, "How embryos work: A comparative view of diverse modes of cell specification," *Development* **108**, 365 (1990).

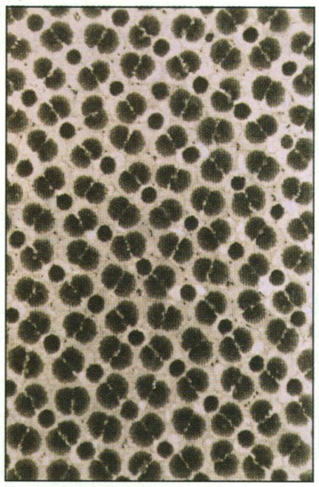
MACHINE VISION

Sunfish Shows the Way Through the Fog

Anyone who has driven in heavy fog knows how difficult it is to see things clearly in a medium that scatters light. Yet fish appear to move with ease through a dense aquatic fog of swirling algae, plankton, sand, dirt, and all sorts of plant and animal debris. Now, after studying the retina of the green sunfish (*Lepomis cyanellus*), researchers at the University of Pennsylvania, Philadelphia, think they know how this creature, at least, accomplishes the feat. And they are trying to copy the sunfish's presumed strategy, known as polarization difference imaging, to improve the vision of cameras in murky conditions.



MICKEY P. ROWE



STEVEN S. EASTER

Double vision. The green sunfish *(above)* has a pattern of double cones in its retina *(right)* that may produce two orthogonally polarized images.

"The really interesting thing is that it has a real application, for example, landing airplanes in fog," says physiologist James Larimer of the NASA Ames Research Center. "Now that we begin to understand how it works, we can actually build sensors that behave just like these animal systems do and extend the range by a substantial amount."

The retina of a sunfish, like that of humans, is a forest of guides focusing incoming light onto detectors. But Mickey Rowe of the university's Institute of Neurological Sciences and his colleagues discovered that there is a crucial difference between humans and sunfish, as well as some other animals, in one type of retinal light guide, known as "cones": The sunfish's cones come in pairs. Each pair transmits light as a single light guide with an elliptical cross section.

Rowe and his colleagues believe that the cone pairs guide light with different polarizations preferentially: Incoming light vibrating parallel to the long axis of the ellipse is transmitted more efficiently than light vibrating across the ellipse. They also found that the cone pairs are arranged in an array, with half the pairs aligned in one direction and the rest aligned in a perpendicular direction. The sunfish therefore seems to be seeing two orthogonal polarized images of the world.

Rowe believes the fish uses the two images to do some clever image processing. When light is reflected off a solid surface, it often becomes partially polarized. Rowe believes the sunfish can filter out light scattered from particles in the water, which has no particular polarization, by subtracting one polarized image from the other. What remains is light that is strongly polarized, and therefore most likely to have traveled, undeviated, from the solid object to the eye.

In an issue of *Applied Optics* last month, Rowe's team, along with Scott Tyo of the university's School of Electrical Engineering, showed that this subtraction technique can be used in a camera system to improve the visibility of some objects in a scattering medium by a factor of 2 to 3. In a bath of milk and water, the team illuminated a circular metal disc with two square patches etched on it that partially polarize light. They took two pictures through the murky water—first with a polarizing filter in one direction in front of the camera and then in a perpendicular direction.

When the researchers subtracted one of the two pictures from the other, the abraded patches consistently showed up more clearly than when they added the images together, which simulates what a normal camera would see. The team saw improvement even when the milk was so concentrated that less than 1% of the light reaching the camera was polarized. "What these guys have is an elegant way of processing polarization information," says David Williams, professor of brain and cognitive sciences at the University of Rochester, New York. This kind of "opponent processing" system is ubiquitous in nature, he says.

There are some problems, however, that the researchers will have to overcome before the system can be put to practical use. For a start, the technique only works if the polarizing filter on the camera is "in line" with the polarization of the reflecting object; otherwise the technique can make visibility even worse. To get around this, Tyo designed a system that automatically rotates the filters to optimize the polarization axes of the camera. Medical imaging specialist Robert Alfano at The City College, City University of New York, also points out that not every reflecting object polarizes light: "If the objects have a preferential axis of reflecting [polarized] light, they can use this method to see it. If not, they can't."

Tyo is aiming to tackle this question, but he points out that many of the objects a machine vision system might want to see—such as a road or the surface of the sea—do polarize strongly. He adds that dielectric materials—which include such things as fish scales—inherently polarize light well. So there is one natural object that polarization difference imaging can definitely see: the green sunfish.

–Sunny Bains

Sunny Bains is a technology writer based in Edinburgh, U.K.