The Right Exposure

Students develop the first living bacteria photographs

Students Aaron Chevalier, Jeff Tabor and Laura Lavery beam with pride when passing around their new pictures. But the photos they're showing off aren't from a backpacking trip around Europe or a hiking expedition in the Rockies. They're passing around some of the first-ever bacterial photographs—living pictures they created on biological film made of *E. coli* bacteria.

The ghostlike photos—images of people, words and buildings—were made when the students exposed Petri dishes holding billions of genetically engineered *E. coli* to patterns of light. A new biological circuit in the *E. coli* gives them the ability to sense light and make black pigment. Each bacterium acts like a pixel on a computer screen, turning black when growing in the dark part of a projection and staying clear in the light.

University of Texas at Austin molecular biology doctoral student Jeff Tabor holds a bacteria-produced photo of an enlarged *E. coli* bacterium—a "self portrait."

The University of Texas at Austin students made the bacterial photographs for the Massachusetts Institute of Technology's annual intercollegiate Genetically Engineered Machine (iGEM) competition, which encourages students to build simple biological machines.

There's no winner of the iGEM contest, but the team was rewarded when their research was published in the Nov. 26 issue of *Nature*, in an issue focused on the field of synthetic biology.

"This is a great example of the emergent field of synthetic biology—using principles of engineering in biology," says Dr. Edward Marcotte, one of the students' faculty advisers and associate professor of biochemistry.

Synthetic biologists like Marcotte and his students and colleagues at the Center for Systems and Synthetic Biology are harnessing the power of genetic engineering to build new biological machines—computers that process information, living systems that manufacture new materials or produce energy, and bacteria that make and administer drugs. They use genes and molecules much like engineers use wires and circuit boards.

"We're making bacteria that are all independently functioning computers and we can get them to do large-scale, complex computations," says Tabor, a molecular biology doctoral student at the Institute for Cellular and Molecular Biology (ICMB).

Escherichia Ellington, an example of bacterial portraiture. The left panel shows the projected image of Dr. Andrew Ellington and the right panel shows the resulting image recorded on the lawn of bacteria.

Marcotte says that the light-sensing circuit used in the *E. coli* could one day be used to design cells that build new human tissue.

"The neat thing is that now you have spatial control of gene expression," he says. "We can make the cells on the left side of a dish do something different than cells on the right. You could imagine that one day you might build tissues in a Petri dish, differentiating the cells based on patterns of light."

"There are hundreds of systems just like this in *E. coli* that we can control," adds Tabor.

He says that bacterial computers aren't likely to match a desktop computer's ability to crunch numbers, but they could interface with the body or the environment.

"They could live in your gut and be programmed to deliver some sort of drug," he says.

But before bacterial computers zip around in our bodies or make new materials, the parts used to build these living machines need to be standardized, says Chevalier, a senior in physics.

"Like in electronics, you standardize all the little components," he says. "Once you know what you want to make, you just go grab it out of the bins. And that's the idea. You want to be able to just grab these biological things, know exactly how they work and put them together to make something happen."

Creating the bacterial photos was an effort by the students to use some of these parts in new ways and to build new circuits that could be used for other applications.

Making bacterial photos

The students got the itch to start their project a little over a year ago, after hearing about the 2004 iGEM competition from their co-adviser, Dr. Andy Ellington, professor with the ICMB and the Center for Systems and Synthetic Biology (CSSB).

"We just tried to come up with the coolest, most interesting application," says Tabor.

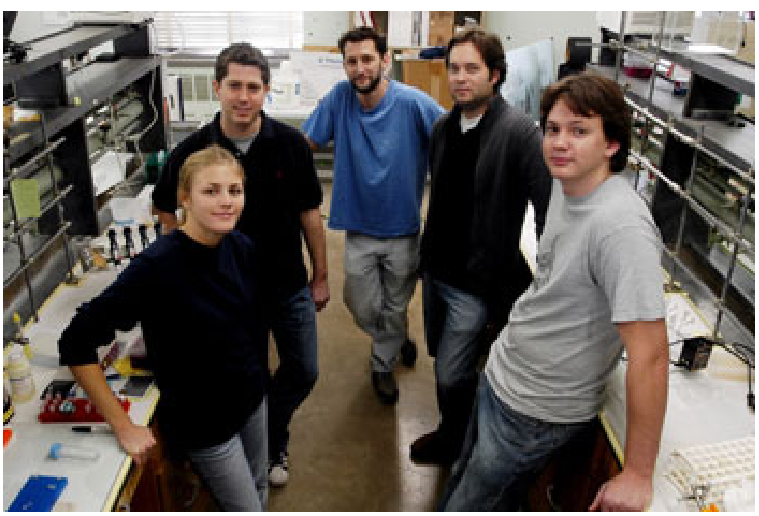
The Texas team, including students Alexander Scouras and Eric Davidson, postdoctoral researcher Matthew Levy, and CSSB researcher Zachary Booth Simpson, decided that they wanted to use *E. coli* to create an outline around a projected light image. But first, they needed *E. coli*—a standard workhorse for genetic engineering in the lab—that could sense light.

They found their engineered microbe in the lab of Dr. Chris Voigt, an assistant professor of pharmaceutical chemistry at the University of California, San Francisco (UCSF). Voigt and his graduate student Anselm Levskaya had engineered a strain of *E. coli* to sense light by adding a light receptor protein from a photosynthetic blue-green algae to the microbe's cell surface.

University of Texas at Austin physics undergraduate student Aaron Chevalier projects an image through the bacterial camera into the incubator.

In order for the UCSF scientists to know if the *E. coli* were responding to light, they also connected the light receptor to a genetic system in the bacteria that leads to the digestion of sugars. When light hits the receptors on the surface of the modified microbes, it turns off a gene that leads to the production of a sugar-digesting enzyme. So in the dark, the microbes digest sugar. In the light, they don't.

The Texas students then engineered a biological film—an agar-filled Petri dish optimized so that the *E. coli* grow evenly throughout the dish. Importantly, the film is infused with a special sugar engineered to turn black when digested. When the bacteria grow in dark parts of the Petri dish, they digest the sugar and produce black pigment. Those in the light don't produce the sugar-digesting enzyme and the film remains clear.



Members of The University of Texas at Austin team. Pictured here from left to right are Laura Lavery, senior in biochemistry; Jeff Tabor, doctoral student in molecular biology; Matt Levy, postdoctoral fellow in the Institute for Cellular and Molecular Biology (ICMB); Eric Davidson, graduate student in ICMB; and Aaron Chevalier, senior in physics.

To take actual photographs with the photogenic bacteria, the students had to do a little standard engineering, too. They needed a camera that could project light onto the dishes of growing bacteria. Chevalier cobbled together the first of the bacterial cameras, which looked something like a tall black smokestack, from old overhead projectors and black poster board.

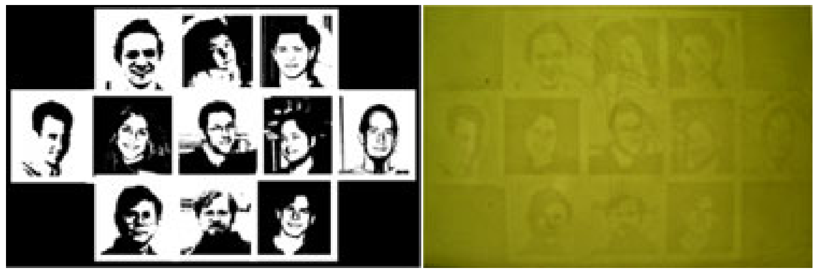
"I built a huge pinhole camera, about seven feet tall, with a dismantled overhead projector," says Chevalier. "At first, we made blobby images and you had to imagine what they were."

But over the course of the year, he and the other students refined the camera. Although it's still made with old bookends, discarded microscope parts and a used incubator, the newest camera is much more compact and takes crisper pictures.

To create a bacterial photo, Chevalier projects red light through a 35mm slide holding an image onto a dish of bacteria growing at body temperature in an incubator. After about 12-15 hours of exposure (the time it takes for a bacterial population to grow and fill the Petri dish), the light projector is removed.

What's left is a living photograph.

"Every time we do this, we get better at it," says Chevalier. "Now, the pictures are really clear." They estimate that the resolution for the bacterial photos is about 100 megapixels per square inch, about 10 times better than a high-resolution printer.



Portrait of the UT Austin/UCSF Synthetic Biology team. The left panel shows the projected image of the students and professors from The University of Texas at Austin and UCSF who participated in the project, and the right panel shows the resulting bacterial photo.

The students still produce a bacterial photo now and again for fun, but they've already been fast at work, nights and weekends, to reach their original goal: bacteria that can compute the edges of an image projected onto them.

"This was a cool demonstration of what we can do," says Lavery, a senior in biochemistry. "Now, we're working on ways to apply this technology to other systems."

Using the same bacterial photography technology, they are engineering bacteria that will create only the outline of a pattern of light projected on them, rather than an entire image. They're also creating what they call "light wires," which uses a Petri dish of *E. coli* as a circuit board to conduct biochemical currents. Cells in the dark will propagate the current, while cells in the light will be repressed.

And they aren't the only ones using the photographic technology. Marcotte says the photography set-up is now becoming a standard tool for engineering bacteria to perform new tasks. The students, for their part, have contributed to the growing field of synthetic biology.

BY **Lee Clippard**

PHOTOS: **Marsha Miller**

BACTERIAL PHOTOS: Aaron Chevalier and *Nature*

Related Sites:

- **Center for Systems and Synthetic Biology**
- **Institute for Cellular and Molecular Biology**
- **Department of Chemistry and Biochemistry**
- **Department of Physics**
- **College of Natural Sciences**

Related Stories:

- **New antibody shows promise as cure for anthrax** - 29 November 2005
- **University of Texas at Austin helped build giant African telescope** - 9 November 2005
- **TRIPS project awarded $4.3 million DARPA contract** - 2 November 2005

- **New discoveries about neuron plasticity linked to learning and memory** - 1 November 2005

Office of Public Affairs
P.O. Box Z
Austin, Texas
78713-7509

512-471-3151
Fax 512-471-5812

Updated 12 December 2005
Comments to utopa@www.utexas.edu