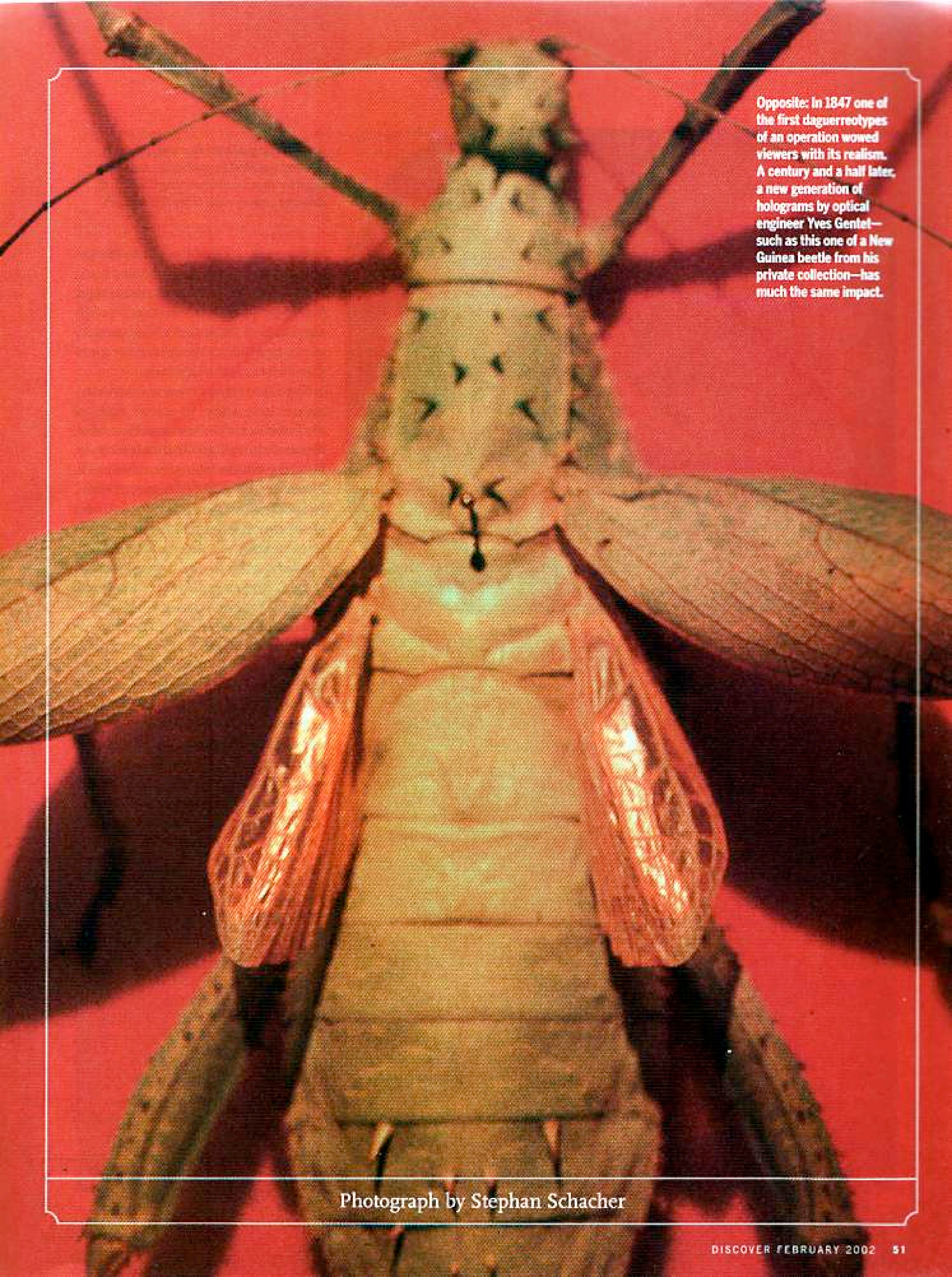


Opposite: In 1847 one of the first daguerreotypes of an operation wowed viewers with its realism. A century and a half later, a new generation of holograms by optical engineer Yves Gentet—such as this one of a New Guinea beetle from his private collection—has much the same impact.

Photograph by Stephan Schacher

The Hologram Revolution

"THEY CANNOT BE CALLED COPIES OF NATURE, BUT PORTIONS OF NATURE HERSELF," SAMUEL MORSE DECLARED. "A GREAT legion of human faces," Walt Whitman wrote. "An immense Phantom concourse—speechless and motionless, but yet realities." In St. Petersburg, Russia, some people were afraid to even look at them, one photographer wrote: "[They] believed that the little, tiny faces of the people in the pictures could see out at them."

True, that was more than a century ago, but if the innocent wonder of those who saw the first daguerreotypes seems incomprehensible now, here is a place where you can recapture it—in the rue Dubourdieu, on the outskirts of the old center of Bordeaux, France. On the third floor of a building that houses a health clinic, down a dark hallway, in a reception area outfitted with secondhand furniture, sits Yves Gentet, a lanky young optical engineer who has invented something amazing. Next to him sits his younger brother Philippe, who came to work with Yves a couple of years ago. Before then Yves worked here alone for six years, with his lasers and his jars of animal gelatin (more on that later) and a No Trespassing sign on his office door. Yves's hangdog eyes appraise you as you appraise the walls of his reception area. They are covered with his holograms.

The walls are an immense concourse of phantoms, of people trapped in amber. There is a Laotian model dressed in a traditional dancing costume, every ornate detail popping from the frame. There is a little girl in a striped shirt, eating a cookie, the crumbs falling from her mouth. If you step to one side you see, behind her raised arm, the collar that was hidden before, with its tiny embroidered chick in a sailor suit; if you bend down and look up you see, above

A hologram made by Yves Gentet for the Musée de l'Optique in Biesheim, France, has none of the oil-smear-like inaccuracy of standard holograms. From almost any angle, it captures life perfectly in three dimensions.

By Robert Kunzig ~ Photography by Stephan Schacher the level of the frame, her mother's smiling eyes. And then there is the box of butterflies, most impressive of all. It is as detailed and as vibrant as reality—but the real box is in the Bordeaux natural history museum. This is just a film sandwiched between two thin sheets of glass.

"It's the dream of holography realized," says Jacqueline Belloni, a chemical physicist and specialist in film emulsions at the University of Paris South. "Whether you're a specialist or not, it's a shock when you see it." Belloni was so flabbergasted when Gentet showed her his butterflies that she included them in a talk she gave at a conference on radiation chemistry. One physicist, who also happened to be a butterfly collector, wandered in late and asked why on earth she was lecturing about a box of lepidopterans. "He wouldn't believe me," Belloni says. "He had to touch it himself." The butterflies seemed not copies of nature but portions of Nature herself.

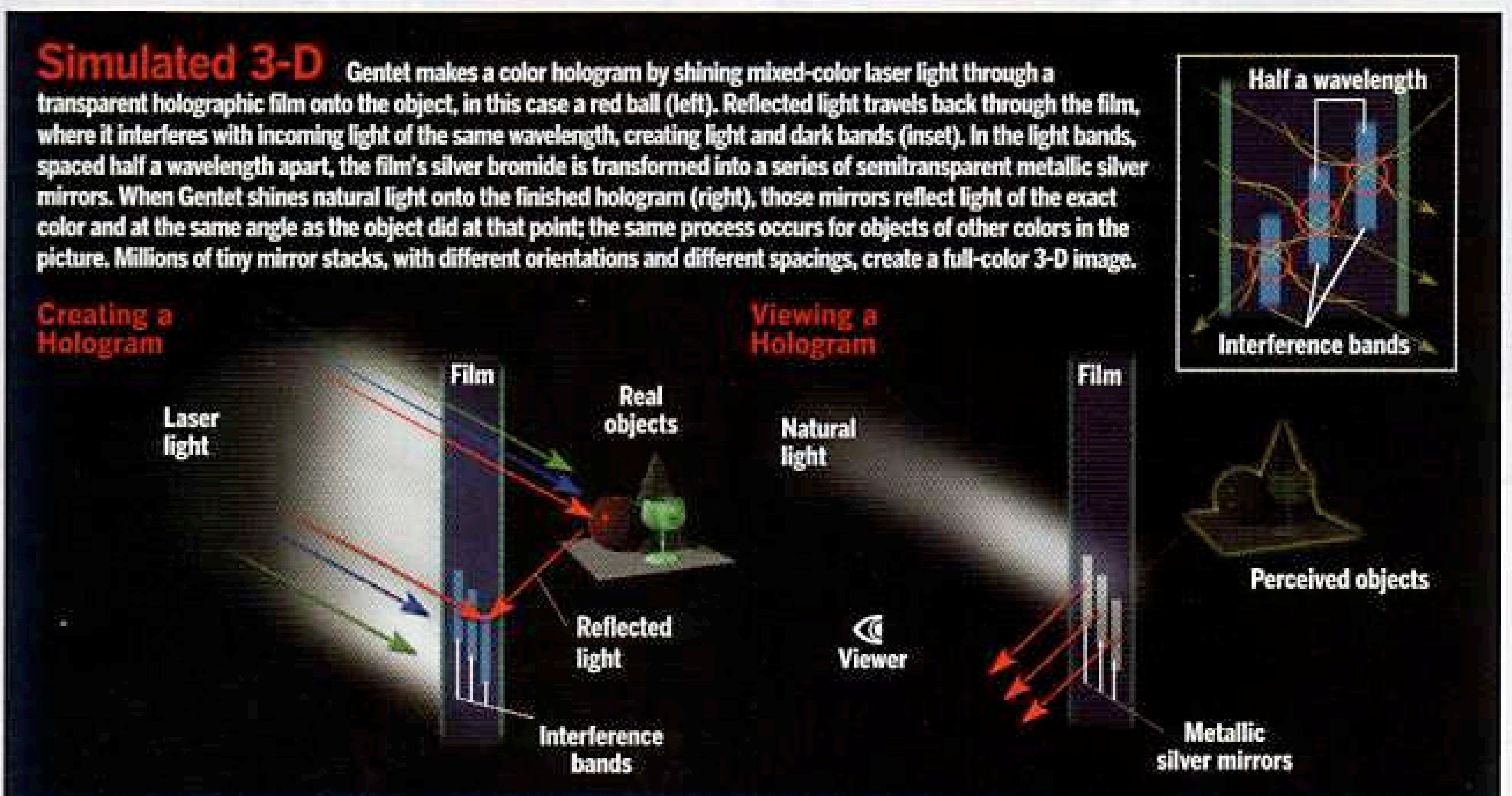
HALF A CENTURY AFTER HOLOGRAPHY WAS INVENTED BY A BRITISH-Hungarian physicist named Dennis Gabor, it still seems mysterious and magical. Partly this is because well-done holograms are so rare; partly it is because the underlying science is convoluted. "My father was a mechanical engineer in Brittany and very intelligent," Yves Gentet says. "But I had to explain it to him many times. And he asked me the same questions many times." Along the way, though, Yves got the hang of explaining it.

Every light wave has three properties. It has an intensity determined by the height of its crests. It has a color determined by the distance between crests—the wavelength. And it has a direction of travel. Daguerreotypes and black-and-white photographs record only variations in intensity; color photographs record variations in wavelengths too. But holograms alone capture light's third property. By recording the direction that light waves travel as they bounce off an object, holograms let us see that object in three dimensions.

Most holograms are monochromatic—they record the intensity and direction of light waves but not their wavelengths. But in the 1960s a Russian physicist named Yuri Denisyuk invented a technique that makes it possible to create holograms in full living color—to record all three properties of light at once. In Denisyuk holography, red, green, and blue laser beams can be mixed together and shone through a transparent holographic film onto the object. The light reflects off the object and back onto the film, where it runs into the original beam. The colliding beams interfere with one another, creating bands of light and dark stacked roughly parallel to the film's surface (see diagram).

Now comes the magical part: At millions of points on the holographic film, those bands are recorded as stacks of semitransparent mirrors, each tilted at a slightly different angle. When you shine natural light on the developed film from the same direction as the original laser beams, all those mirrors reflect light at precisely the same angles at which it originally bounced off the object. Thus when you look at the film, you see the object floating behind it, in full 3-D glory. Even better, you see it in full, true color. The spacing of the mirrors in each stack is such that each stack reflects only the wavelength of light that created it; the other wavelengths are canceled out.

That's the idea, anyway. In practice, until Gentet, no one had made a holographic film that could do it justice. The best-known holographic film, made by Crown Roll Leaf and a few other companies, is used to create "rainbow" holograms



Simulated 3-D Gentet makes a color hologram by shining mixed-color laser light through a transparent holographic film onto the object, in this case a red ball (left). Reflected light travels back through the film, where it interferes with incoming light of the same wavelength, creating light and dark bands (inset). In the light bands, spaced half a wavelength apart, the film's silver bromide is transformed into a series of semitransparent metallic silver mirrors. When Gentet shines natural light onto the finished hologram (right), those mirrors reflect light of the exact color and at the same angle as the object did at that point; the same process occurs for objects of other colors in the picture. Millions of tiny mirror stacks, with different orientations and different spacings, create a full-color 3-D image.

GRAPHIC BY MATT ZANG

recorded on polyester film. You've seen that film on credit cards, but you were in no danger of thinking the eagle was real. It just isn't light sensitive or color faithful enough to re-create reality. Another type of emulsion, bichromate gelatin, is even less light sensitive, but it has been useful in holographic readouts such as those that enable fighter pilots to keep their eyes on the enemy rather than the fuel gauge. Gentet worked on such a system at Sextant Avionics in Bordeaux until 1992, when his lab folded and he was laid off.

At the age of 29, Gentet was left with a career as a freelance holographer, and he decided to make the best of it. Several French companies helped him out with the lab space in Bordeaux. Gentet spent his first couple of years there building all his own equipment from scratch, in particular a portable holographic portrait camera that he envisioned as his cash cow. He had just about finished it when Agfa, the sole manufacturer of the film his camera required, decided to get out of that business. Having invented a camera Gentet found he now needed to invent a holographic film as well.

Gentet's years of teaching himself film chemistry and tinkering alone in his lab have resulted in an emulsion he calls Ultimate. Its basic structure is that of ordinary black-and-white film: an emulsion of silver bromide grains, which are very light sensitive, dispersed in animal gelatin. When light strikes the grains, the silver bromide is converted into metallic silver—the stuff of mirrors. The main difference between Ultimate and other emulsions is that its silver bromide grains are extremely fine—around 10 nanometers across, or 1/10 to 1/100 as big as the grains in ordinary film. The fine grains allow Ultimate to record tremendous detail. They also allow it to record red, green, and blue simultaneously in a single emulsion layer, as interdigitating stacks of tiny mirrors.

Gentet won't say how he makes the emulsion; none of his techniques are protected by patents. "We've perfected the emulsion that everyone has been looking for for 30 years," he says. "It's savoir faire—know-how." But it's not as if he is asking people to take his assurances on faith. If seeing is believing, then standing in his reception area and looking at his walls, you have to believe him.

TWO SUMMERS AGO, THE GENTET BROTHERS TOOK THEIR BUTTERflies and a few other images to a holography conference in Austria. When it came time for their talk, the trade newsletter *Holography News* reported later, "140 seasoned holographers made a collective, awed intake of breath." Afterward, Philippe says, "the room emptied as people came to look at our holograms." "People were subjugated," Yves recalls. "All these experienced holographers put their hands behind the glass plates as if the images were a mirage. They were glued to them."

The triumph was long in coming: Since Yves invented Ultimate, the world has not exactly beat a path to his "hole in Bordeaux" (his words). Gentet thinks his holograms would be a perfect way to make a replica of Chauvet Cave, the site of spectacular prehistoric paintings that the public isn't allowed to see, but he can't get an appointment with the proper

Yves Gentet adjusts an optical bench in his lab in Bordeaux, France. The bench holds some 120 optical instruments used in the making of Gentet's most complex multichannel holograms.

authorities to present his idea. He has proposed setting up a portrait studio at Disneyland Paris to create a gallery of visiting celebrities, but the negotiations have stalled. The basic problem, Gentet thinks, is that he has great holograms but no hologram factory, and French investors are too risk-averse to build one. He and Philippe have been thinking of immigrating to Quebec, where it may be easier to find willing investors. Their father, now retired, is ready to go with them.

Lately, though, things have been looking up. Gentet has found an American partner who has the machinery to copy an Ultimate master onto a polymer made by DuPont. For reasons Gentet doesn't fully understand, the results, though not of Ultimate standards, are far superior than if the polymer were used to record the hologram in the first place. The DuPont copies can already be cranked out on an industrial scale, and the same may soon be possible with Ultimate itself. Meanwhile, this past November, Gentet's holograms won two major awards from the International Hologram Manufacturers Association.

Somehow Gentet's images will get out; they're too powerful to remain cooped up in the rue Dubourdieu forever. Even Gentet himself is spooked by them sometimes. "When I made a portrait of my father, I couldn't sleep that night," he says. "It was the shock of having my father's head in a box."