Depth Perception

Ramesh Raskar '02 brings a limitless vision to the field of augmented reality, whose boundaries are nowhere in sight.

by Paul Gilster

There is a place between light and shadow that changes the way we look at things. Ask any traveler — the Taj Mahal at dusk is a different place than the Taj Mahal at noon. And it was natural that this classic example of changing visual textures — a building whose marble hues vary with the intensity of light — should have seized the imagination of Ramesh Raskar '02 (PhD). The India-born computer scientist, working at UNC with computer graphics gurus Greg Welch and Henry Fuchs, has created what he calls "shader lamps" that use light the way sculptors use clay, as a plastic, creative medium.

Clay, in fact, is what makes up a small white model of the Taj Mahal that Raskar used as his palette, painting it with the changing light from different projectors. It's the interplay of the digital and the physical: An object (the model) is illuminated by computer-calibrated light. What you see is a building that changes as the projectors control the shadings of dawn, noon and dusk. Take that idea into the business world, and a car dealership could model a single car in a variety of colors and finishes, while a clothing salon could offer the latest styles and fabrics projected onto a neutral store manikin.

We've entered the world of "augmented reality," a discipline now championed by Raskar in his position as senior research scientist for Mitsubishi Electric Research Laboratories (MERL) in Cambridge, Mass. Augmented reality is a step beyond "virtual" reality, in which the user needs goggles or other kinds of equipment to experience computer-generated effects.

"While virtual reality completely replaces your surroundings with a synthetic world, augmented reality says my world is pretty interesting on its own," Raskar

Kathleen Dooher

said. "All I want to do is to add some information to what I see. It can be as frivolous as trying to find a matching pair of socks, or as serious as a nurse looking for the right medicine in an emergency."

Engineering meets art

Or as pedestrian as turning on your television. Think of the weather report, as the meteorologist gestures at frontal boundaries and developing rain on a map laden with temperatures and pressures. A trip to the TV studio reveals the truth: The TV personality actually stands in front of a blank blue surface. High-tech wizardry couples the image of the person with the digitized imagery of the map.

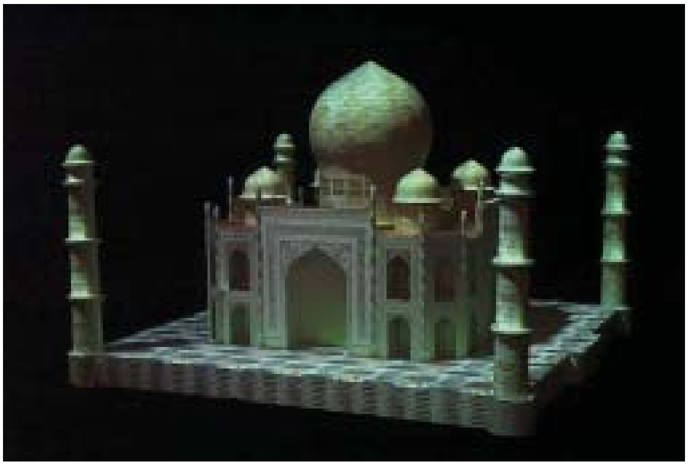
Take Raskar's shader lamps into the business world, and a car dealership could model a single car in a variety of colors and finishes. A clothing salon could offer the latest styles and fabrics projected onto a neutral store manikin. 'All I want to do is to add some information to what I see.'

Ramesh Raskar '02 (PhD)

When you start combining the real and the virtual in a seamless way, you're on the road to augmented reality. It's engineering that can verge on art, a multidisciplinary way of sensing and shaping the world around us that has carried Raskar from a town 200 kilometers northeast of Mumbai (Bombay) to a leadership position in a field whose boundaries are still being charted.

And it draws on diverse technologies. How, for instance, does augmented reality find that nurse's medicine? One solution is through what Raskar calls "Radio Frequency Identity and Geometry" (RFIG), a system that projects images onto physical objects while connecting to tiny identification tags with photosensors that are embedded in the objects. Shine an appropriately equipped handheld projector on a stack of medical supplies and each radio tag is activated, displaying its location and other information. Put the same system into everyday products and you've made the household a place where digitized information can be displayed on top of pantry shelves or alongside bookcases.

Melding the virtual with the real is a practice Raskar focused on in his doctoral work, done primarily with Greg Welch, a research associate professor. The Taj Mahal model originally was assembled by Welch's wife when she was a girl. "Ramesh realized there was a continuum of things you could project on," Welch recalled. "We're used to seeing flat video on TV screens, and we accept that. Now we see something that is, as far as our eyes can tell, the real object. We see the physical Taj Mahal, but its surfaces are visibly changing." Welch envisions extending the technology to life-sized dioramas such as museum displays projected onto Styrofoam blocks shaped, for example, like the objects in an Egyptian tomb. Digital projectors then bring the scene to life, the advantage being that such dioramas would be readily changeable for the next exhibit.



RAMESH RASKAR/GREG WELCH

A clay model of the Taj Mahal and, below it, the same model enhanced with shader lamps. In the interplay of digital and physical, the model is "painted" with computer-calibrated light from multiple projectors. The view of the Taj Mahal changes as the projectors control the shadings of the building at dawn, noon and dusk.

Where Raskar works, pushing the boundaries of technology is part of the job description. As an industrial research laboratory, MERL emphasizes breadth, flexibility and adaptability, said Joe Marks, the director of MERL. Marks likes to quote a Raskar phrase: "Research should ride the technology curve." In a lab setting, that means anticipating what's coming two to seven years down the road. "The idea is to have something interesting ready to go when the technology develops that fits your idea," Marks said. "It's like Wayne Gretzky said about hockey. You skate to where the puck will be."

The puck, of course, is ever moving, and according to Marks, the average time between a patent application and its intro-

Photos Courtesy of Ramesh Raskar

At left is an example of Radio Frequency Identity and Geometry, a system that projects images onto physical objects while connecting to tiny identification tags with photosensors that are embedded in the objects themselves. Objects can be located quickly with a handheld projector that activates the radio tags.

Below right, the pocket projector can connect to various devices, such as digital cameras, PDAs and cell phones. The projector lets you project an image onto a nearby surface, below left, making it much more viewable than on a device's tiny screen.

duction into a commercial product is seven years. Which is why Raskar remains in motion. In numerous papers and presentations, he continues to probe the outer edges of light. A Raskar design for a modular projector for cell phones or PDAs is already on sale. It can take a photograph stored on the device and project it onto a nearby surface, surmounting the limitations of tiny screens. Another Raskar project: projectors that adapt to their surface, whether slanted, rough or painted, canceling out distortion to deliver a perfect image.

One of the challenges the young scientist presents, say those who work with him, is simply keeping up the energy that makes moving between concepts like these so apparently effortless. Paul Dietz, who works with Raskar at MERL, has supplied ideas and hardware for projects involving multiple, adaptive projectors, work that extended from aligning images on projection surfaces to RFIG. "Team Ramesh," said Dietz, "is an intense experience," recalling the researcher's habitual push to

complete work for upcoming conferences, a 'round-the-clock marathon that sometimes starts a month before deadline.

If Raskar might be called a driven man, he's also a bit of a showman, given to projects that enable eye-catching demonstrations at trade shows, as attendees of the annual SIGGRAPH computer graphics conference learned in 2004. "Ramesh came to me saying we needed to do something memorable," Dietz said. "I joked that we could dress up like the Village People and sing 'R-F-I-G' to the tune of *Y-M-C-A*." Next thing I knew, I was in

front of 5,000 people, wearing a cowboy hat and showing why I'd never make it on *American Idol*."

The world as painted scene

A fascination with the creative uses of projection goes back to Raskar's childhood in India. Growing up around technology — his father was an electronics engineer — he became entranced with mathematics and recalls thinking of the world in computer graphics terms before he ever saw a PC. "I really believed the world was just an illusion," he said, laughing. "I think many

Courtesy of UNC Department of Computer Science/Photo by Larry Ketchum

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Ramesh Raskar '02 (PhD)
recalling his childhood

children have this notion. I thought there was nothing behind me; the world was being painted as I looked at it. And if I could turn around quickly enough, I might fool the creator of these paintings and see the world taking form."

But the fascination with the world as painted scene persisted. It seems a naive notion, but as he finished college in India and worked his way through advanced degrees at the University of Iowa and then Chapel Hill, the young scientist realized it was the core idea of virtual reality. The computer paints the world only where you are looking. Henry Fuchs was the catalyst who sparked further ideas. Fuchs had created a mantra: Let's learn to control light every millimeter, every second. Lights, in other words, can become "smart," can be turned into projectors to communicate and inform. Fuchs spoke of using a "sea of cameras" to project and reconstruct a 3-D scene at a remote location.

Out of such thinking grew the "Office of the Future," a collaborative effort whose UNC component is led by Fuchs and Welch. The project investigates tele-immersion, replicating environments by projecting information onto blank spaces that create a

Dan Sears '74

The "Office of the Future," at top, creates virtual environments not unlike Raskar's notion of the world as painted scene. The man in the foreground "meets" with the digitized image of a woman in Armonk, N.Y., and another virtual collaborator in Sitterson Hall. The project's UNC component is led by Raskar's co-advisers, professors Greg Welch and Henry Fuchs, above.

PHOTOS COURTESY OF RAMESH RASKAR

The "flutter shutter" camera's action is novel. Rather than opening and closing the shutter once, the researchers flutter it open and closed in a mathematically selected pattern. The camera preserves detail from the scene that would have been smeared out in a normal photograph. The results are striking: A photograph of a moving car, blurred beyond the ability to recognize small details, becomes a clearly defined Volkswagen with a readable license plate.

virtual meeting place. Part of the initiative involves display surfaces that are not flat but shaped like the scene to be re-created, much in the mode of Raskar's Taj Mahal. In a 1998 paper on this work, Raskar described techniques that would allow meetings to occur as if the participants all seemed to be sitting in the same office, no matter what their actual location. "That paper put Ramesh on the map," Joe Marks said. "It was a visionary paper, and the amazing thing is that he's gone on to display the same kind of vision again and again."

Eighteen patents later, Raskar's work with cameras and projectors is changing how we use light to see and understand. The non-photorealistic (NPR) camera is a case in point. Shoot a picture with a flash, and you create a shadow. Raskar looked at shadows and saw that multiple flashes from different angles could create a series of shadows that would define the shape of the object. The result is a camera that can detect depth. You may not need one for vacation photos, but the capability is useful for doctors doing procedures such as endoscopies, in which abnormal shapes signify potential tumors. Paleontologists have put the NPR camera to work in Greenland, where it helps to reveal minute details of dinosaur bones that are all but impossible to see in conventional photographs.

So multitudinous are the researcher's ongoing projects that Jack Tumblin, an associate professor of computer science at Northwestern University who is now working on a book with Raskar, almost forgot to mention the NPR camera when describing the emerging field of computational photography, in which both men are playing a major role. But Tumblin sees the technique as significant, a merging of computer vision, in which computer resources are brought to bear on an actual image, and computer graphics, in which a mathematical description is used to create a picture. And he says it was one of the things that drew Raskar's work to his attention in the first place.

Computational photography changes everything we thought we knew about cameras, even in the digital era. Most digital cameras today simply replace conventional film with a grid of picture elements — "pixels" — rather than fundamentally altering what the camera can do. But what if we could bring computer power to bear on problems such as over- and under-exposure, or contrast, or motion? Any amateur photographer has had the disheartening experience of composing the perfect shot, only to find that hand motion, or the movement of something in the scene itself, has hopelessly blurred the image. Tumblin and Raskar presented a paper at this year's SIGGRAPH conference on what they call "coded blur photography," a technology becoming better known by its informal name, the "flutter shutter" camera. The exposure time is long, but blurs are a thing of the past.

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would have been smeared out in a normal photograph. The results are striking: A photograph of a moving car, blurred beyond brand or license plate recognition, becomes a clearly defined Volkswagen with a readable plate. "We want to move toward more direct measurement of visual appearance, to what it is that people perceive in the scene," Tumblin said. "Features that are visually important to human beings — the edges of things, shadows, boundaries and textures — will become machine readable."

The result is a photograph that is essentially assembled out of data. And while today's photographer can edit a picture with software such as PhotoShop, computational photography goes much further. The "edits" that occur use information that is actually in the scene; changes bring out only what is really there. The picture also can extend over time, not a single photograph but a photograph in movable pieces. "It's a good bet from all this," said Tumblin, "that the still photography/motion picture distinction will one day vanish."

If the camera's newfound flexibility resembles anything, it is a kind of hugely enhanced artist's brush. The computed scene is one that can be startlingly lifelike, or shaped into imagery that is as surreal as a Dali painting. "There is always a tension between realism and what appeals to a human," said Shree Nayar, T.C. Chang Professor of Computer Science at Columbia University in New York. A frequent collaborator, Nayar has been probing computational techniques with Raskar and examining the potential for creating new types of imagery. "This is a new medium altogether," Nayar added. "Or one should say that this is a new set of tools that allows a professional or even an amateur photographer to edit after the fact. And yes, there is a boundary here where you get into the realm of art."

A fruitful imagination

Nayar, who praises Raskar for his ability to see connections between seemingly disconnected fields, is hardly surprised that this digital malleability should inspire the researcher's latent artistry. Raskar is a habitué of art shows involving technology, a lively scene in New York and Boston that creates interactive displays involving computer graphics, cameras, sensors and projectors. A recent project was "Camera Non-

KATHLEEN DOOHER

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Photo," a display in which the NPR camera assembles images of gallery-goers that are like richly detailed cartoons.

But the latest is a display called Instant Replay, one that takes off on a project Raskar is developing for Mitsubishi called Luminetra. The word "netra" is Sanskrit for "eye"; Luminetra, then, refers to an eye that perceives changes in light. The technology, displayed playfully in an air hockey game in Raskar's artwork, enables slow-motion replays of events that are superimposed on the place they actually occurred. "We embed a little electronics in the puck and something that's looking down on the table, and the experience is transparent. When somebody scores a goal, they see the slow-motion replay," Raskar adds. As always, the idea has ramifications beyond the immediate. Luminetra could be used, for example, in medical rehabilitation, where sensors can be embedded in clothing that capture the motion of a recuperating person throughout the day.

For a man whose work is reinventing the ways we interact with light, Raskar also nurses a deep-seated passion for journalism and the act of writing. His new book on computational photography, co-authored with Jack Tumblin, is due out this summer, and the duo continue to define the field by teaching short courses at conferences such as SIGGRAPH. The book will not be Raskar's first. Despite a constellation of ongoing projects at Mitsubishi, he found time to co-author *Spatial Augmented Reality: Merging Real and Virtual Worlds* (2005), and he continues to ponder yet another title that draws on a newspaper column he used to write while in college back in India. Tentatively called *The Small Things in Life*, it's to be a collection of tips — how to track your luggage, how to find the best parking spot, how to maximize your time. The latter being a concept this indefatigable scientist has clearly mastered to perfection.

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For more about Raskar, his work and the long-exposure "flutter shutter" camera, go online: www.merl.com/people/raskar/raskar.html; www.merl.com/people/raskar/deblur/; *and* www.cs.unc.edu/~raskar/

Raskar, 36, doesn't slide easily into any pigeonhole. Driven to marathon work sessions as project deadlines approach, he's also the playful showman who will put his team through a singing skit at a computer conference. He's a fan of technology-oriented art shows and an eclectic author.