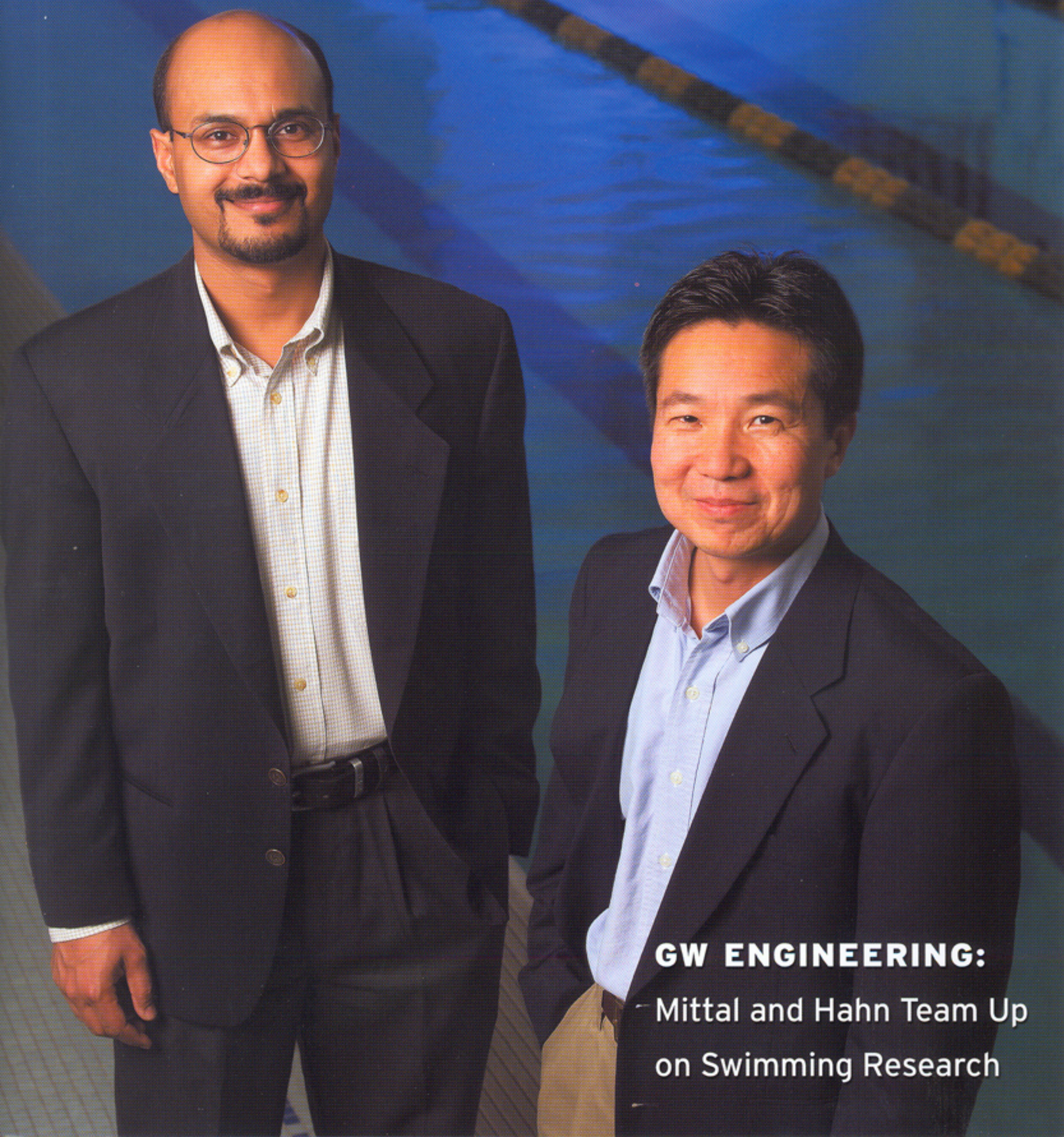


Spring 2005

The George Washington University SYNERGY

School of Engineering & Applied Science



GW ENGINEERING:

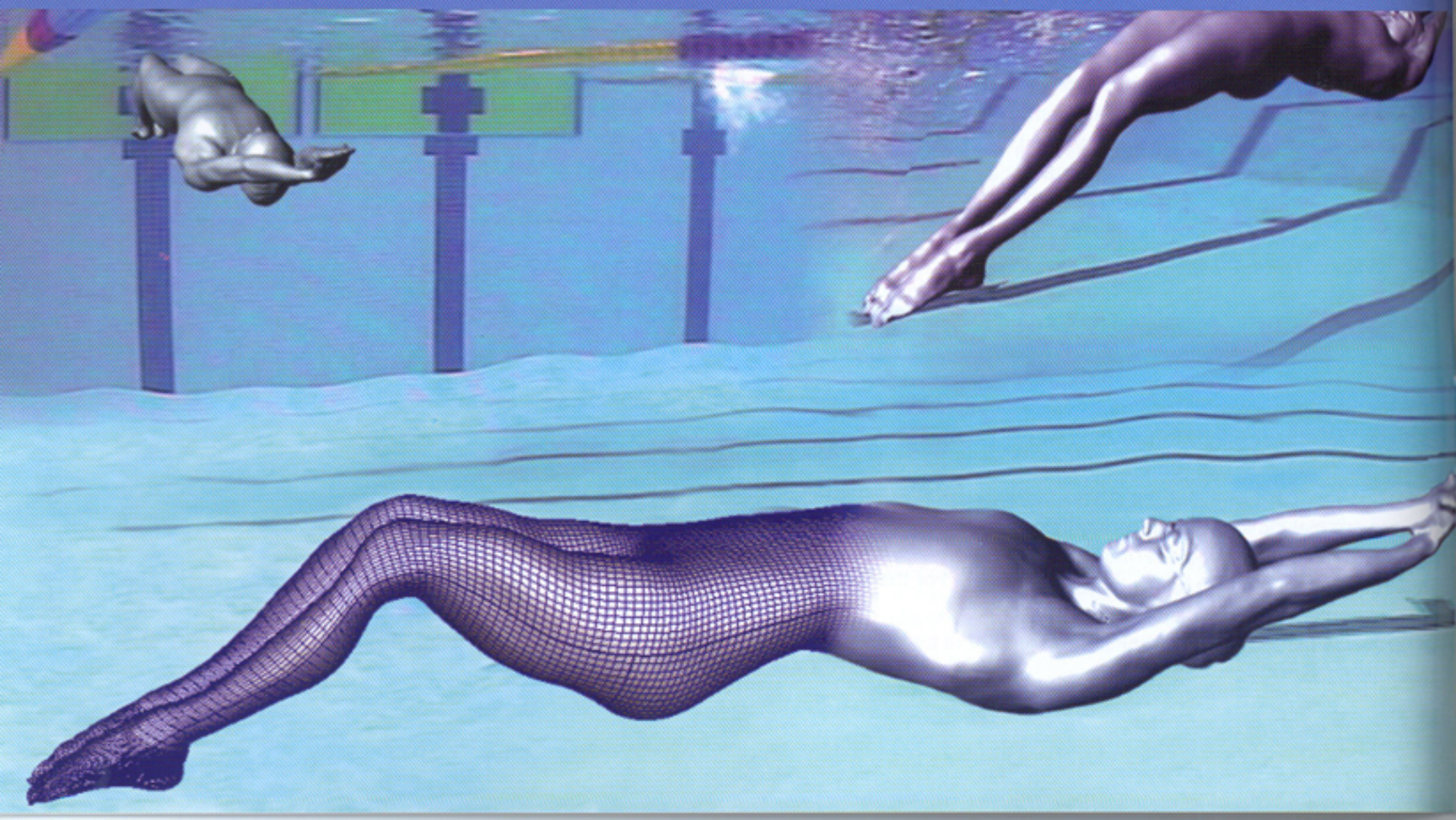
Mittal and Hahn Team Up
on Swimming Research



Mittal and Hahn

Decode

the Secrets of Swimming



COVER STORY:

An Olympian Task: Teaching Humans To Swim Like Fish

Mr. Mittal, Using **SUPERSTARS** and **SUPERCOMPUTERS**, Dives Deep for Answers

By Barry Newman Friday, August 13, 2004

ATHENS—Upside down, underwater and moving backward, Natalie Coughlin swims faster than almost anybody who isn't a fish. The 21-year-old Californian's talent for mimicking her fellow

mammal—the dolphin—has given her an edge when pushing off the pool wall in all three of her Olympic sprints: the butterfly, backstroke and freestyle.

What makes Natalie kick? Ms. Coughlin, a psychology major at University of California, Berkeley, has a theory. "I don't know much about physics," she says. "I just know that if I make my amplitude a little smaller, I should travel faster. It's kind of intuitive."

Her answer isn't enough for Rajat Mittal. The professor of mechanical and aerospace engineering at George Washington University has developed a deep interest in Ms. Coughlin's dolphin kick. A superstar's winning move, he thinks, deserves to be pored over by a supercomputer—and, in Washington, he has one.

For the past year, Prof. Mittal, 37, has been working to load it with a three-dimensional incarnation of Ms. Coughlin undulating in a virtual pool. Even at 100 billion calculations a second, the task is huge—and a measure of how far the technological backfield of today's Olympics will go to win a few more medals. Prof. Mittal's goal, simply put, is to take the guesswork out of perfection.

"Up till now, what is good or bad in all human performance is based on intuition," he says. "Once science comes into it, some of this fuzziness about what's best and what's not will be gone."

On Prof. Mittal's office shelf, a bluegill sunfish is pickling in a jar. He has a grant to help the U.S. Navy study how the fish swims with its little front fins. The Navy wants someday to swap a machine for the moody dolphins it sends out on search mis-

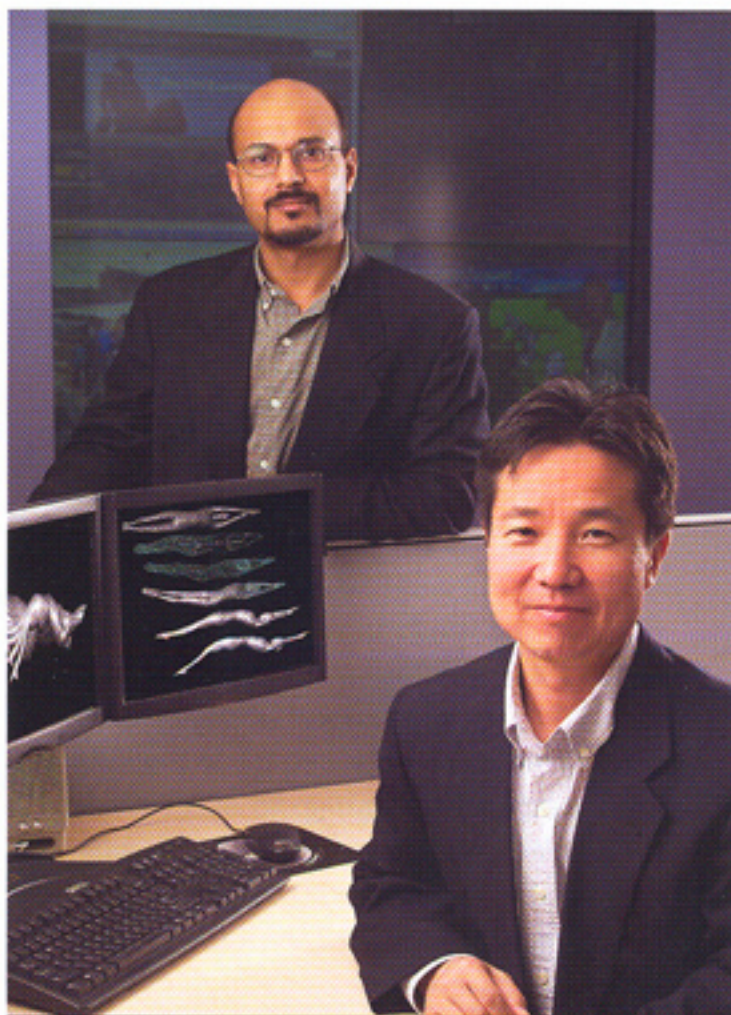
sions, and that will require new levels of computer simulation, not for objects like submarines, but for things that flap and squiggle under water.

With the Navy paying the bill to drop a fish into an \$800,000 supercomputer, Prof. Mittal figured he may as well drop a fishlike human in, too. He hooked up with Russell Mark, a former college swimmer who, at 24, is "biomechanics coordinator" for USA Swimming, the sport's ruling body. His job is to explore how flesh and fluid might cooperate to make swimmers move faster.

"Look across a pool," says Mr. Mark. "Every swimmer will be using different techniques because every swimmer is taught different techniques." It has been so at least since Duke Kahanamoku came up with a new kick and broke the Olympic freestyle record at Stockholm in 1912. But there are no set answers. Even James "Doc" Counsilman, a pioneer of scientific coaching who died this year, had to amend his theory that a hand slicing across a swimmer's body under-

water pulls the swimmer the way propellers pull airplanes; the hand, it now seems, is still mostly a paddle.

Before computers, coaches shaped strokes the way engineers sculpt cars—by watching swimmers in a flume, the watery equivalent of a wind tunnel. Coaches today watch laser-scanned swimmers in digital flumes. That's how Speedo tested its new full-body swimsuit. Mr. Mark almost did as much.



TEAMING UP: Professors Mittal and Hahn (foreground) join forces for interdisciplinary research into the biomechanics of swimming.

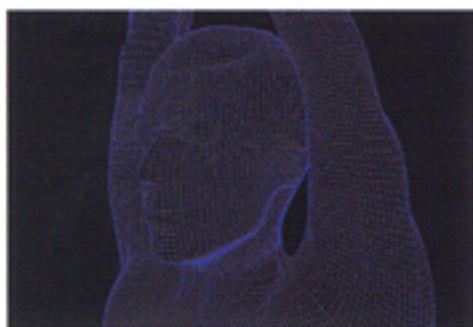
He had two of his champs, Gabrielle Rose and Lenny Krayzelburg, laser-scanned in Hollywood. But then he got a call from Prof. Mittal, and jumped into the next dimension.

Laser-scans have a failing: They don't move. Scanned dry-land athletes can be wired up, animated and pasted into videogames. But they aren't fighting a fluid. Water's disorderly effect on motion makes picking apart a swimmer's progress hugely more complex.

"Swimmers push the water, and the water pushes back," says Prof. Mittal. "It all comes down to turbulence. If we could compute every instant in a stroke, we could understand it."

"For us, this now
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ALMOST AT THE EDGE OF IMPOSSIBLE."



That's why he needs a supercomputer. Mr. Mark donated the Rose and Krayzelburg scans, and a set of videos from USA Swimming's flume in Colorado Springs. One showed Ms. Coughlin dolphin-kicking. When he saw it, Prof. Mittal knew she was the swimmer he had to use.

"She swam straight, maintaining an even depth," he says. "All fish do this, passing a wave through their bodies from head to tail. This was it—the natural-selection stroke, the best way to swim."

Lacking a scan of Ms. Coughlin, Prof. Mittal assigned a student to superimpose her videoed body, frame by frame, onto the scan of Ms. Rose. He then asked James Hahn, director of GWU's Institute for Computer Graphics, to essentially insert a skeleton, enabling the scan to move. The output is a goggled, silver phantom, dolphining across a black screen, trailing a thin red line undulating across a graph—sort of like the markings on an electrocardiogram.

Three-dimensional, observable from all angles, this creature is Prof. Mittal's raw material. All he has to add next is water. Pushing the limits of his field-computational fluid dynamics, he plans to factor in every swirl and counterswirl produced by an ever-changing sequence of motions known as a single stroke. To account for every eddy within every eddy, he will break each stroke into 20,000 units and perform 200 million calculations on every one.

By reducing Ms. Coughlin to her elements, Prof. Mittal aims to attain an absolute awareness of what makes her so fast. "Does her body size naturally put her into the right range of amplitude?" he asks. "Should small swimmers kick at higher frequencies than big swimmers? If so, how much higher? That's what we want to know."

Don't expect an answer in Athens. The supercomputer will be mincing the dolphin kick for three more years, at least. And when it eventually applies its soft-

ware to strokes that pierce the water's surface, the variables will multiply. Yet Prof. Mittal and his partners see a day coming when swimmers will have their Olympic body mechanics customized without ever getting their feet wet.

Some variables will never be downloaded: willpower, for one. And coaches who believe that natural strokes are best left natural may not want their swimmers diving into virtual pools.

"Some of our people don't care about technique at all," says Mr. Mark. But Natalie Coughlin, whose stroke is as natural as they come, isn't one of them. "You can't change physics," Ms. Coughlin says. "You might as well figure out how it works." She thinks the water in Prof. Mittal's supercomputer is just fine.

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The article reprinted above appeared in the Wall Street Journal on August 13, 2004, the opening of the 2004 Olympic Games. Although the Olympics faded from our collective consciousness just two weeks later, many Olympic hopefuls and their coaches have been hard at work since then, trying to maximize their chances of success for 2008. SEAS professors Rajat Mittal and James Hahn have also remained hard at work, making progress on their research in support of Olympic swimming.

One afternoon this winter, Mittal and Hahn sat down with the Synergy editor to discuss their progress on the USA Swimming project and to explain why

their work gets the attention of people outside the swimming community, particularly those in the biomedical engineering field.

SYNERGY: *What progress have you made on your swimming-related research since last summer?*

MITTAL: IBM has something called the Blue Gene project, which the company started to regain and sustain America's lead in supercomputing. IBM's Blue Gene/L computer is now listed as the fastest supercomputer in the world and they're looking for interesting and challenging applications for it. After reading about our swimming research, the director of the Blue Gene project

approached us, because they were interested in finding out whether we'd like to run our swimming calculations as one of the test applications on their new computer. We're currently in discussions with them and hopefully out of that will come collaboration with IBM. Over the summer, students and researchers from our research group will go to IBM for a few weeks to try to get our computer code working on the fastest computer in the world.

SYNERGY: *What is the significance of this potential collaboration with IBM?*

MITTAL: For us, this now makes very possible something that was almost at the edge of impossible. The biggest

computer we have in our lab is a 32-processor computer. With this computer, we were estimating that a single calculation of the dolphin kick would take us two to three months. IBM will give us access to a 1,000-processor computer, on which we should be able to get one good-quality simulation every week or so. If we're able to use the computer even for a month, it will allow us to do three to four calculations and put us months ahead of schedule. Analysis of those calculations will keep us busy for another year after that.

SYNERGY: *The Wall Street Journal article didn't elaborate on the role of computer graphics in the work you've done with USA Swimming. What is the role of the computer graphics research?*

HAHN: Initially, the role of the graphics was primarily to support the CFD [computational fluid dynamics] research; that is, to provide Rajat [Mittal] with the motion as well as the laser-scanned body shape geometry for each swimmer. We now have a full research project involving three students working on the computer graphics part of the problem.

Jean Honorio Carrillo is working on the body surface geometry. We have laser-scanned geometry of two swimmers, and Jean is working on a new approach to morph those two prototypical bodies into any specific swimmer from a set of anthropomorphic measurements.

Tina Ma is working to capture the motion of the swimmers from video. The idea is to extract from the video the positions and orientations of the joints at discrete points in time. Once we extract this position orientation information, we can generate a three-dimensional representation of the motion, which can be used both for visualization and analysis of the swimming motion. Extracting the motion of swimmers has proven to be extremely difficult. The standard technology used for movies or games has been unsuccessful when working with water, due to obscurations from splashes.

TAKING THE GUESSWORK OUT OF PERFECTION: "If we could compute every instant in a stroke, we could understand it," says Professor Rajat Mittal.

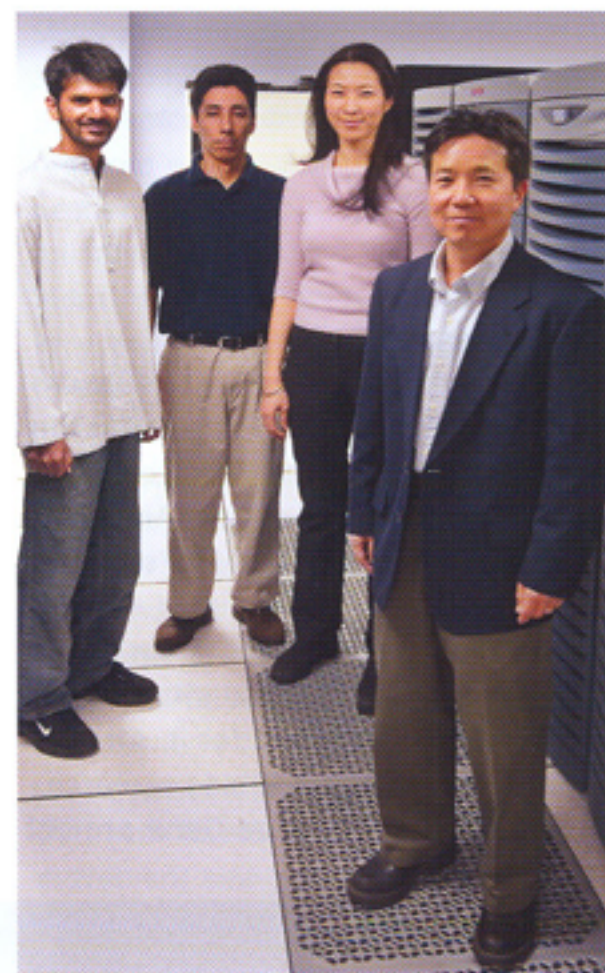


GRAPHICS BY GW INSTITUTE FOR COMPUTER GRAPHICS

YOUNG BLOOD:

Left hand photo: Professor Rajat Mittal gathers with doctoral students Meliha Bozkurtas (*left*) and Alfred von Loebbecke (*center*) in front of the super-computer they use for stroke calculations.

Right hand photo: Professor James Hahn (*right*) and students--Samir Roy (*left*), Jean Honorio Carrillo (*second from left*), and Tina Ma--handle the project's computer graphics.



We're experimenting with the use of computer vision to extract 3-D information from several synchronized video sequences. The technology comes from an approach we've been developing to track the surface of the laryngeal cartilage to guide surgeons during surgery.

Our third student, Samir Roy, is working on the visualization and analysis of the motions. Right now, the way that coaches and swimmers analyze the motion is just by looking at videotapes. By generating a 3-D representation of the same motion, we have a virtual laboratory in which the motions can be visualized using a variety of techniques. For example, we can view the motion from any angle; we can put tracers on any part of the body to show its trajectory; we can even make arbitrary measurements on various parts of the body as a function of time.

The idea behind this is that once we have a large database of different people swimming different styles, we can create a library of motions. We hope that we can then generate some hypothetical motions--extrapolated from our library of motions--that are ideal for a particu-

lar swimmer, based on that specific swimmer's physiology. USA Swimming has expressed interest in supporting these computer graphics approaches as a way to impact not only Team USA and its efforts leading to the next Olympics, but also as a way for coaches and athletes to train at all levels of competition. They have expressed an interest in working with the GW swim team, and we hope to bring them into this project in the future.

SYNERGY: *So how do the two of you actually collaborate?*

HAHN: Before Rajat [Mittal] is able to do the CFD [computational fluid dynamics] simulations, he needs a 3-D representation of the swimmer and how the swimmer is moving through space and time. We provide that shape information as well as how that shape changes as the swimmer is going through the stroke.

MITTAL: Ultimately, the goal on the fluid dynamics side is to figure out what part of the body is producing the thrust, how modifications in the stroke improve the speed and effi-

ciency, etc. That information will be produced using the fluid dynamics software.

HAHN: The results of the CFD calculations can then come back to us for visualization along with the swimming motions.

SYNERGY: *Does anyone else work with you on this project?*

MITTAL: Yes, one of my doctoral students, Alfred von Loebbecke, is the key member of our research team. I also had a high school student, Hersh Singh, from Thomas Jefferson School of Science and Technology, work with me the last two summers, and he actually did one of our earliest simulations. Other people who are contributing to this work in our group are Meliha Bozkurtas, who is a doctoral student, and Haibo Dong, who is a research scientist. It's important to mention that there's a team at Rutgers [University] that's a partner in this project, too. The Rutgers team essentially does what we do--examine the fluid dynamics--except with real experiments in the swimming pools. So this really brings together

three different facets of the whole science of swimming, and that is unique as far as I know.

SYNERGY: *Does your research have broader applications, beyond its potential impact on Olympic swimming?*

MITTAL: This research gives us an opportunity to develop some unique software tools that can be easily applied to other areas in biology and biomedical engineering. The essential feature in the swimming simulations, if I boil it down, is fluid flow interacting with a complex, organic, moving shape; and our software can handle this as easily as it can handle any other organic entity, including for instance the heart, the lungs, or the trachea.

Take, for example, the production of voice in the human larynx, which is essentially a result of air interacting with vocal folds. The same software that simulates flow past the swimmer is being used to simulate airflow in the larynx, and we hope it can one day be used to predict the outcome of laryngeal surgery. We are also considering using this software to understand blood flow in fibrillating hearts. So, you see, the potential applications of this software are really quite diverse.

HAHN: The visualization and analysis of motion is something that we've actually done before in relation to physical therapy and in collaboration with the NIH [National Institutes of Health]. We hope

that the work we are doing in this project can impact the study of human motion for physical therapy, sports medicine, psychology, anthropology, and dance. Our research on body surface geometry has the potential to affect the way the movies or the computer games industry generate large numbers of human shapes. By generating a random set of anthropomorphic measurements distributed over a particular population, we have the potential to automatically generate large crowds, armies, or virtual extras with a wide variety of body shapes.

SYNERGY: *Do you have any other thoughts to share on the impact of your research?*

MITTAL: The academic community likes to pick up what it calls "challenge problems," problems that really challenge the state-of-the-art of the field. Some times they might not have any immediate applications, but the challenges are big enough that in trying to achieve them, you end up developing a lot of new tools and technologies that find use in other places, just as our software for the swimming project is being used in simulation of voice production for people who have suffered strokes.

Secondly, in all of this, we can't forget that we're in the business of educating students, and this provides a very nice avenue for grabbing the attention of students. A student in mechanical engi-

neering might not be interested in fluid mechanics because he or she might find it difficult or too mathematical, but if I put the same problem in the context of Olympic swimming, suddenly it can turn on the interest of that student.

HAHN: Aside from the technical contributions in the respective fields, the research has motivated a whole new set of interdisciplinary collaborations. We have learned from each other and learned to work with each other.

MITTAL: We found complementary skills where we would never have looked for them before.

EDITOR'S NOTE:

Support for this project is provided by USA Swimming and GW's Institute for Biomedical Engineering. The institute also provides funds for a variety of other interdisciplinary pilot research activities. To learn more about the institute, please see the article on page 16. For more information on this research, e-mail Professors Mittal or Hahn at mittal@gwu.edu or hahn@gwu.edu, or visit <http://project.seas.gwu.edu/~fsagmae/Swim%20Pages/MAIN.htm>

THE STROKE:

Images of a swimmer at different points in her stroke allow coaches to visualize and analyze the swimmer's motion.

