Computing

The interplay of biology and information technology is transforming how and why computing is done.

ADVANCES IN INFORMATION technology usually boil down to a few classic story lines. There's the story of Moore's Law, in which computers steadily gain performance, use less power, and fall in price. Then there is the story of how the exchange of data between far-flung computers gets easier every day. Look at this year's TR100 innovators in computing, which spans both hardware and software, and you'll see evidence of these trends at every scale, from tiny, single-electron transistors to computer grids that gird the globe. But look again and you'll also see a bold new story emerging: the increasingly productive interplay between computing and biology. ■ More and more biological processes are being understood by viewing them in terms of information processing. And computer models are increasingly helping biologists design new experiments and gain insights into the workings of complex biological systems. In turn, computer scientists are looking at living organisms as the ultimate models for new approaches in decentralized computing. All in all, it's a cross-fertilization that was practically unheard of until a few years ago.

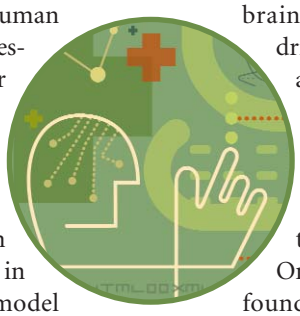
Perhaps nowhere are advances in computing helping biology more than in the field of genomics. Consider, for example, the genome-parsing programs that **Serafim Batzoglou** has developed at Stanford University. The software takes full advantage of all the cheap computing power and memory hitting the market. "Now, we can easily hold the entire human genome in main memory," Batzoglou says. With "small clusters of cheap Pentium machines," he adds, it has become possible to rapidly search that data for specific DNA sequences. Comparable to scanning volumes of the *Encyclopedia Britannica* to locate a specific string of 10 words, this search is crucial to understanding genetic differences between individuals and between species. The biggest speedups in the search process, Batzoglou says, have come from "designing clever algorithms."

In another example of the infotech-biology convergence, startup Sana Security in San Mateo, CA, is building a computer security scheme that is rooted in the study of how organisms protect themselves from biological intruders. **Steven Hofmeyr**, Sana's founder and chief scientist, explains that studying immune systems through the lens of digital information processing has yielded several powerful algorithms that help protect banks of computer servers from hackers and computer viruses. Biology has taught researchers that software distributed across many machines that can teach itself the difference between benign activities and malicious attacks, for instance, may

BY JOHN VERITY » ILLUSTRATION BY CELIA JOHNSON

provide better security than centrally managed, hard-coded approaches. Information systems are getting too complex for humans to manage effectively, Hofmeyr says, so it's important to build software that can learn and take care of itself.

While researchers like Hofmeyr are inspired by the workings of biological systems, others are inspired by the human body itself. **Cynthia Breazeal** at MIT's Media Laboratory has built robots whose mechanical faces appear to express human emotions in response to the gestures and facial expressions of people they encounter. She's using her robot called Leonardo to explore how people and robots might one day communicate. NaturalMotion cofounder and CEO **Torsten Reil** and MIT's **Jovan Popovic** have each developed software to generate realistic animations of the human body in action, with an eye toward applications in video games and filmmaking. Reil's programs model the physics, musculature, and behavior of human bodies as they run, jump, or balance on wires. Popovic's code serves as an artist-in-a-box, instantly creating sequences of drawings as an animator drags a digital object with a computer mouse.



For some, nature is not only an inspiration but a collaborator. It has long been known, for instance, that certain molecules naturally assemble themselves into highly regular, periodic structures when deposited on flat surfaces. If researchers could figure out how to control this process, it could provide a simple way to make novel nanoscale hardware devices and materials for ultradense storage. At the University of Toronto, **Ted Sargent** has figured out how to apply electric fields to assemblies of molecules as they self-organize, prompting them to form nanostructures of a specific design. His methods could yield a way to mass-produce photonic crystals used to more precisely route light, a feat that could revolutionize optical communications.

In most areas of computing, however, it's still sheer human brainpower—not inspiration from biology—that is driving innovation. **Vipul Ved Prakash**, founder of the anti-spam company Cloudmark, has come up with a way for—potentially—millions of people to jointly decide which mass e-mails are junk. He first released his online voting mechanism, called Vipul's Razor, as open-source software that's free to use and that anyone can inspect and modify. Once the program gained a substantial following, he founded Cloudmark to produce a commercial version. "Open source gives people an outlet to publish their stuff, get lots of users quickly, and prove their product," says Prakash. "Then they have a better chance of getting [venture capitalists] to take a look and invest."

Whether the TR100 are working to bring about the convergence of biology and information technology or are worried about more mundane matters, such as spam, their work shares a goal: to expand the impact of computing. In the next few pages, you will read how they are adding to the classic story lines of information technology.

TR100 Startups in Hardware and Software

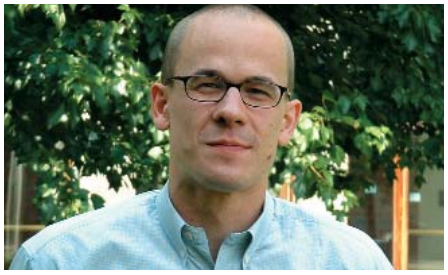
INNOVATOR	COMPANY FOUNDED/COFOUNDED	STRATEGY/MILESTONES
Geoffrey Barrows	Centeye (Washington, DC)	Visual sensors that use neural-like circuits to detect obstacles and guide unmanned aircraft
Ian Clarke	Cematics (Santa Monica, CA)	Software for distributed secure networking and artificial intelligence
	Uprizer (Santa Monica, CA)	Peer-to-peer software that distributes content within large organizations; raised $4 million in 2001
Andrew Heafitz	TacShot (Cambridge, MA)	Method for snapping aerial photos from small rockets and sending them wirelessly to a laptop computer
Steven Hofmeyr	Sana Security (San Mateo, CA)	Software, modeled on the immune system, that enables computers to defend against viruses and hackers; has raised $12 million from venture capitalists
Mike Horton	Crossbow Technology (San Jose, CA)	Microelectromechanical sensors, a.k.a. "smart dust," that self-assemble into wireless networks; has taken in $13 million from Intel Capital and other investments
Kevin Lee	LNL Technologies (Cambridge, MA)	Integrated photonic and optoelectronic microchips for communications and computing; has raised at least $7.1 million in seed funding
Desmond Lim	LNL Technologies (Cambridge, MA)	See above
Michael O'Connor	IntegriNautics (Menlo Park, CA)	Hands-free, Global Positioning System-based apparatus for automatically steering tractors and other heavy equipment; has raised $18 million from venture capitalists and institutional investors
Joe Pompei	Holosonics (Watertown, MA)	Narrowly focused beams of high-quality audio for use in consumer products
Vipul Ved Prakash	Cloudmark (San Francisco, CA)	Spam-filtering software for use by individuals and corporations; raised $4 million in venture funding in July 2003
Torsten Reil	NaturalMotion (Oxford, England)	Software that generates lifelike, 3-D animations of human characters for computer games and films; technology will be used in *Troy*, a forthcoming movie starring Brad Pitt
Tim Sibley	StreamSage (Washington, DC)	Software for searching and managing audio and video files that recognizes sequences of spoken words
Lorraine Wheeler	Botzam (North Billerica, MA)	Utility software for Palm-OS-based personal digital assistants

Maximilian Riesenhuber, 33

MIT

Programs computers to recognize objects the way the human brain does

THE HUMAN brain can recognize a dog as a dog, but teaching a computer that trick is daunting. As an MIT postdoc, Max Riesenhuber researched the brain's object recognition processes, then led a team that wrote software to mimic them. Called HMAX, the program is accurate enough to save physiologists time and money in studying brain disorders. To test the model, researchers might show it an illustration of a composite creature, such as a catlike dog. HMAX categorizes the animal's features as more or less catlike or doglike, sums those probabilities, and issues judgments remarkably consistent with human subjects'. Now, scientists are using HMAX to craft better experiments to help explain brain disorders like prosopagnosia—the inability to recognize faces. Unraveling such afflictions is Riesenhuber's main goal. But his software also advances computers' ability to recognize objects, a key to artificial intelligence. HMAX might even help recognize satellite images. Riesenhuber, founder of MIT's Motorcycle Club, is also a principal of GeoPhoenix in Cambridge, MA, which markets a handheld computer interface that can access content by zooming and panning, helping users navigate small screens.



Heike Riel, 32

IBM

Built large, bright, organic video displays using materials dismissed by contemporaries

HEIKE RIEL left a furniture-making apprenticeship to study physics. A PhD later, she has built the world's largest full-color display that uses organic light-emitting diodes (OLEDs)—paving the way for a new generation of vivid-color, affordable, flat-panel televisions and computer monitors. Her 20-inch screen is brighter and more energy efficient than any other screen on the market. Cell-phone displays and other small screens have used OLEDs for streaming video, but larger-scale applications have proven elusive. In a large screen, each of millions of light-emitting pixels requires several transistors, and the transistor matrix had been difficult to manufacture uniformly. Researchers had steadfastly tried to improve the polycrystalline-silicon transistors, claiming that the alternative—amorphous silicon—would break down at the high currents needed for pixel emission. But Riel and her colleagues fashioned the OLEDs at IBM's Zürich lab so that inexpensive amorphous-silicon transistors drew less current and, therefore, remained stable and generated far less heat. Riel, in particular, tinkered with the width of the pixels' thin organic layers, allowing significantly more light to be emitted. "People didn't believe it could be done," she says.

Linda Rottenberg, 35

Endeavor Global

Helps entrepreneurs in emerging nations turn innovations into businesses

LINDA ROTTENBERG believes that startups are the best way to create jobs and stimulate growth in economically struggling nations. To prove that contention, she cofounded Endeavor, a nonprofit that helps entrepreneurs in emerging countries access networks, training, and everything else they need to convert innovative ideas into companies. Endeavor invests no money itself. Instead, CEO Rottenberg and five other New York-based staffers coordinate 24 employees in Argentina, Brazil, Chile, Uruguay, and Mexico—and soon in South Africa. Those employees encourage prominent local businesspeople to find funding, give advice, and otherwise open doors for entrepreneurs. In the past year Rottenberg's group has developed Web chat rooms where executives and entrepreneurs can compare notes. Endeavor claims that since 1997 it has supported 121 companies, which have generated more than 9,000 jobs and $363 million in revenue. Startups that are profitable within a few years often reward Endeavor with a small percentage of revenues or equity. Endeavor's notable technology startups include Patagon.com, an Argentine online finance pioneer that was sold for $700 million, and Taho, a Brazilian wireless-communications company. "People worldwide with good ideas are calling us every day," Rottenberg says.

Ted Sargent, 30

University of Toronto

Fashions photonic circuits that could speed voice and data to homes

TELECOM NETWORKS are half-hare, half-tortoise. Conversations and data blaze down fiber-optic cables but slow to a crawl when they encounter electronic switches at network junctions. Photonic crystals, which can manipulate photons much as semiconductors manipulate electrons, are the best hope for clearing such roadblocks. While others are exploring them, Ted Sargent is close to building practical devices. Sargent came to the University of Toronto as a grad student in 1995, joined its faculty in 1998, and in three years was awarded a coveted Canada Research Chair position. His chief advance is a process to specify and guide the growth of photonic crystals—a mix of electrochemistry, microchip fabrication, and holographic printing. Sargent etches a holographic pattern into an electrically conductive film that coats a glass plate. Then he electrifies the film, generating a holographic "tractor beam" that attracts latex beads and stacks them into a photonic crystal. Sargent has fashioned hair-thin rows of crystals that could act as circuits, and Nortel eagerly awaits proof they can manipulate photons. If so, photonic crystals could speed up the telecom network, including the "last mile" of cable to homes.