Nanotechnology: The Growing Impact of Shrinking Computers

David Geer

Nanotechnology helps make the pervasive aspect of pervasive computing possible. One obstacle to putting computers everywhere is size. You can put a desktop computer, well, on your desktop. But you can't put it in your bloodstream (such pervasive computing applications are indeed being explored). Shrinking computers makes it possible to put them almost anywhere.

To envision nanotechnology's potential, think about building things from the molecular level up. At that level, you can build in characteristics and capabilities that aren't readily apparent. Fueled by numerous drivers (see the sidebar), projects from data storage to power generation to medical exploration are all putting nanotechnology to use.

CONSUMER GOODIES THAT NEVER FORGET

In IBM's Zurich Research Lab, scientists are engineering a new data-storage technology called Millipede. Instead of a thousand legs, this Millipede has thousands of silicon tips, each with an apex of about 10 nanometers (nm), many times thinner than a human hair. These tips serve as read-write heads for recording and retrieving data inside the Millipede storage device.

The tips store data by punching holes into an extremely thin plastic film. The tips are heated and a small force is applied to make indentations of about 10 to 20 nm. The tips can read and erase data as well. "This fits into a tiny form factor with data densities on the order of one to three terabits per square inch," says Peter Vettiger, who initiated the project with Nobel Laureate Gerd Binnig. That's many, many times more memory than the smallest storage that devices have today.

Millipede's envisioned form is about the size of a secure digital card—a memory card the size of a postage stamp weighing less than an ounce—and it will have the storage capacity of dozens of gigabytes. "It is a considerable improvement in terms of capacity," says Vettiger.

Its initial application will be in consumer electronics as a high-end flash memory technology, such as for mobile applications in cameras, camcorders, laptops, mobile phones, and MP3 players.

"You will have your entire library of music with you in your MP3 player," says Vettiger. You will be able to download, store, and play movies on your cell phone and store, all the pictures you ever take on your camera.

These memory specs are ideal for consumer electronics but could eventually extend to areas such as data archives or everyday data storage, says Vettiger. The storage cards might appear in consumer electronics around 2009.

The silicon tip research has culminated in a working laboratory prototype that demonstrates many features necessary in commercial products, but further research is required and under way. Mobile devices are subject to sudden shock and vibration and adverse temperatures. Stored data must remain stable over time despite these challenges.

The silicon tips also must retain their sharpness for at least 10 years to read and write data for a reasonable product life. "These are the kinds of things the Millipede team is working on," says Vettiger. "We are quite confident that we will be able to meet all of these requirements."

TINIEST TRANSFORMERS

In October 2005, Singapore's Nanyang Technological University announced the development of one of the world's tiniest transformers for electronic gadgets. According to the university, at only five times the thickness of a human hair, the transformer is one-

in brief...

Robo-Teddy: Today's Stuffed Toys, Tomorrow's Intelligent Agents

Benjamin Alfonsi

It's a sure sign that pervasive computing has entered a new era—in some ways even more telling than the PC's dominance or wireless communication's emergence. The good old-fashioned teddy bear has become an intelligent agent.

Computer scientists are now using stuffed toys as intelligent agents in an array of applications—from bunnies and squirrels that serve as cell phone answering devices to bears that function as "living" log recording devices.

What's the significance of equipping stuffed toys with emerging technological capabilities? And how could this type of research affect computing on a larger scale?

PLUSH APPEAL

Call it the cute factor. According to Stefan J.W. Marti, HCI researcher

This computerized, plush squirrel answers cell phone calls, takes messages, and alerts its owner to important calls or new voicemail.

at MIT Media Laboratory, people react positively to embodied agents, such as stuffed toys, mainly on an emotional level. "Although those reactions are often unconscious, they are statistically highly significant," he says.

Marti has developed a computerized stuffed squirrel that fields cell phone calls, takes messages, and alerts its owner through movement to important calls or new voicemail (see http://web.media.mit.edu/~stefanm/research.html#current). It's wireless and mobile. He says he chose the squirrel in part because of its cuteness; there's also a rabbit model.

Marti has received numerous suggestions for embodiments, including traditional-looking robots as well as characters such as Darth Vader and The Terminator.

"They all are possible options since my work is only assuming that the embodiment is afforded with the ability to express itself with nonverbal cues, which is possible in many ways," he says. "People have different preferences as to how lifelike, fluffy, or realistic the embodiment should ideally be."

Marti says that cultural attitudes have also influenced his approach. "We noticed that people from Asian

third the size of other transformers developed thus far.

"We are excited about the possibilities for this technology in the design and production of a multitude of consumer electronics," says Yeo Kiat Seng, head of the division of circuits and systems in NTU's School of Electrical and Electronic Engineering.

The NTU transformer is built into the integrated circuit (IC)—a microchip wafer or a consumer electronics computer chip—whereas traditional transformers are a separate component. According to Ng Aik Kiat of NTU corporate communications, this lets manufacturers save space and production costs, which translates into smaller, cheaper consumer electronics such as mobile phones, radios, TVs, and computers.

NTU is seeking partners to bring the transformer, three years in the making, to production. "Our next step is to bring it from the lab to the streets, where consumers can realize its benefits," says Yeo. NTU researchers hope to follow this breakthrough by incorporating entire systems of electrical and electronic components into ICs.

PLASTIC SOLAR POWER STORAGE

Shrinking gadgets plus added functionality equals a growing demand for longer-lasting, nanosized power sources. "A lot of cadmium batteries now have carbon nanotubes as electrodes," says Vinayak Dravid, a professor in the department of materials science and engineering at Northwestern University.

A nanotube is a long, round carbon structure made of graphite molecules. Nanotube electrodes improve the energy density in these batteries, affording longer battery life.

Nanotechnology is springing up in nontraditional power storage, as well. Konarka's Power Plastic is an example of a solar-power storage material, also referred to as *plastic solar*, says Daniel McGahn, the solar-materials developer's executive vice president. Plastic solar offers several advantages over silicon solar cells.

According to McGahn, plastic solar is made of conducting polymers (yes, some plastics do conduct electricity) and nano-engineered materials that can be used to coat surfaces. Konarka's plastic solar material provides DC current that

cultures, especially Tokyo and Seoul, have a much more relaxed perception of robots and animatronics than Western cultures."

FRIENDLY INTERFACE

Kenji Mase, professor of information architecture and technology at Nagoya University, is using a teddy bear—what he refers to as a "stuffed toy interface"—in his research into computer-mediated communication. The bear has dual functionality as a log recording device and a daily partner.

Explains Mase, "The log is used as a review of what the toy watched and listened to as well as to augment review of [the bear's] tactile interactions with humans, such as holding and petting."

Mase says the bear's intimate interfacing functionality, part of its role as daily partner, will be a necessary feature of future robots, whatever the robot's target tasks.

Cynthia Breazeal, associate professor of media arts and sciences at MIT, is developing the Huggable—a therapeutic interactive bear for hospitalized children. The bear could also be used to assist children exposed to traumatic situations, such as Hurricane Katrina.

Breazeal and her colleagues were inspired by animal-assisted therapy and affective touch interactions' health benefits for hospital patients (see http://robotic.media.mit.edu). The scientists believe the Huggable could augment such programs.

"Living animals can only visit for a limited period of time," explains Breazeal. "The Huggable would allow us to understand if longer-term interaction provides additional or different benefits to hospitalized children.

"Also, given that the Huggable is in reality a sophisticated robot with significant computational power, we're discussing with [health professionals] how the Huggable might play a role in helping hospital staff with their job, such as monitoring patient activity."

According to Breazeal, children's visceral reaction to the bear is a fundamental part of the study. "It cannot sound like a machine with noisy motors and gearboxes. We want it to feel as much as possible like holding an organic creature," she says.

If nothing else, research using stuffed toys might signal what the future holds for ubiquitous computing and animatronics. Marti predicts that sensor nodes and microcontrollers will increasingly be built into everyday objects, including clothes, jewelry, and, of course, stuffed toys.

"Everyday objects will become technologically more complex so that an abstraction layer may be necessary in addition to the actual computation," he says. "This layer may well be autonomous and proactive agent technology."

Mase believes that emerging technologies will allow computational communication in the future to move from merely transmitting factual information to recording and sharing everyday experiences, exchanges, and emotions.

devices can store, use immediately, or convert to other forms of energy.

"Because Konarka's technology utilizes a wider range of the light spectrum than conventional solar cells, all visible light sources—not just sunlight—can be used to generate power," says McGahn.

Power Plastic makes it possible to seamlessly build battery-power regeneration into any powered product that will be exposed to some kind of light. "Solar no longer needs to be a separate aftermarket system constrained by weight, size, rigidity, or installation concerns," says McGahn.

You can find Power Plastic in supplies and equipment provided to the US Army and the US Air Force. These include small, mobile AA battery chargers for use with soldiers' handheld
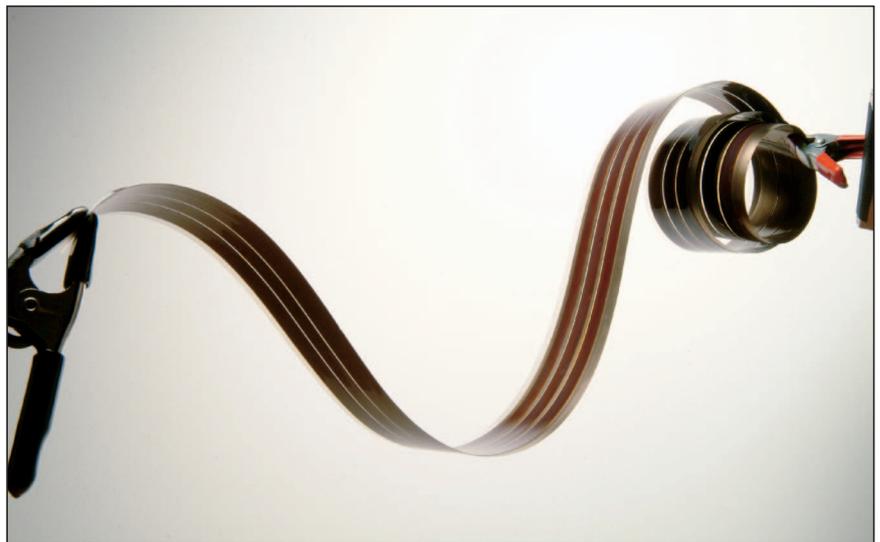
Konarka's light-activated Power Plastic is made from conducting polymers and nano-engineered materials. The materials are coated onto a surface in a continuous roll-to-roll process similar to how photographic film is made.

WHY SMALLER IS BETTER

Creating nanostructures—transistors—of a much higher density with very high throughput is a growing need, says Vinayak Dravid, a professor in the department of materials science and engineering at Northwestern University. Processing for pervasive devices and small distributed systems is fueling this demand.

In addition, today's computer-chip manufacturing processes aren't fault tolerant (any flaw or defect has the potential to break down the system). Nanoscale lithography techniques, on the other hand, have the potential to produce fault-less or fault tolerant chips.

These flaws appear in the physical process of making computer chips. "Our research is in the area of creating tools and devices that can analyze structures and defects at the atomic level," says Dravid.

According to Dravid, many engineering challenges are associated with really translating this research into high-level production chips with high through-put—not fundamental scientific challenges, but challenges in putting the transistors together at that small a scale. Although numerous other engineering challenges exist, positioning structures at the sub-50-nanometer (nm) length is the biggest problem. "That truly reaches the limits of current lithography technologies," says Dravid.

Still, chips are built at the 50-nm scale today. And, according to Dravid, there is a fair bit of optimism that it can be scaled down two times in the next five years. "So, we are looking at 20 to 25 nm in that time frame," he says, adding that there have been demonstrations of proof of concept down to a handful of nanometers, but those are still in the laboratory.

devices, tents that draw power from light outdoors to power equipment indoors, and self-powered sensor systems in which the housing is made of Power Plastic.

Potential consumer products that parallel military applications include battery chargers for cell phones, MP3 players, cameras, and PDAs. The next step is making casings out of Power Plastic for the devices themselves, says McGahn.

Security and environmental sensors, lighting systems, and camping and recreational gear are all feasible commercial applications of plastic solar. In three to five years, Konarka expects to see its solar plastic in roofing materials, awnings, and window treatments, says McGahn. In this decade, he adds, the company sees plastic solar in textiles woven from photovoltaic fibers. Photovoltaic fibers would be capable of turning light into direct current.

According to McGahn, plastic solar

will have its greatest initial impact on portable electronics, sensor networks, and architecture. Plastic solar can support electronics with more functions for longer periods regardless of form factor. Sensor networks will span larger areas, detect and transmit more information, and work efficiently with fewer maintenance issues because of fewer power constraints. Architecture will be seamlessly imbued with the ability to generate power. You can make solar low cost and make it blend in visually, says McGahn.

Most of Power Plastic's obstacles are in the marketplace, says McGahn, but it's edging its way in, one niche application at a time.

SPEAKING OF SENSORS

NASA Ames Research Center's short-term nanotechnology efforts focus on chemical and biosensors using carbon nanotubes, says Meyya Meyyappan, director of the NASA Ames Center for

Nanotechnology. "The chemical sensors are used to look for gases and vapors like carbon dioxide, methane, NO_2 (nitrogen dioxide)," says Meyyappan, not only on other planets but also on Earth.

The biosensors are applicable to water-quality monitoring in human environments such as space stations and exploration vehicles, says Meyyappan. Both of these examples have potential threat-detection applications in homeland security, he adds. Advantages in addition to the sensors' tiny mass include greatly heightened sensitivity to gases and biological triggers over currently available equipment.

Very small sensors are crucial in aerospace because of the rising cost per pound of sending up material. "For Mars and beyond, it will cost US$100,000 per pound," says Meyyappan. To reduce launch costs, NASA is also reducing to nanoscale instrumentation and any other applicable items.

Making an individual sensor is comparatively easy when you consider the supporting technologies you must build around sensors to make them of any use. "The sensor gives you a signal when a gas or vapor gets on to the conductive channel of the sensor, but the sensor is only one component," says Meyyappan.

Take, for example, a handheld sensing unit that airport security personnel might use. To help the sensor perform accurately, the device would require a preconcentrator to concentrate the incoming mixture of the gas or vapor being sensed. "You may need a small micropump or a fan or a blower to pump this in. You need a signal processing chip, as well," says Meyyappan.

The sensors' low power consumption is also an important factor. "It's not like you have a wall socket on Mars that you can just plug into and use any amount of power," says Meyyappan.

These sensors can be expected in production in three to five years. "Companies are already talking to us about licensing this technology," says Meyyappan.

MEDICAL WONDERS

In the longer term, NASA's nanotech research has applications in the medical arena, such as using carbon nanotubes to develop an x-ray source. Such an x-ray source could then be used to develop x-ray tubes. These tubes are useful in x-ray spectrometers and could have applications in the security (replacing airport x-ray machines) and biomedical fields, says Meyyappan.

Research is also under way in using nanocomputers to maintain healthy human cells. "A human cell has a dual function," says Alexander Yabrov, professor of biological research at Rutgers University. "It functions according to its own needs; it also functions according to the needs of the organism. Good health exists when the needs of the organism and of the cell are optimally satisfied."

Yabrov proposes using nanosized computers in the bloodstream to monitor and care for human cells. According to Yabrov's vision, a physician would trace, monitor, and maintain balanced cell health through informa-

Carbon nanotube x-ray tube for use in an x-ray diffraction/fluorescence spectrometer. It consists of a film of carbon nanotubes, which emits electrons upon application of an electric field. (figure courtesy of NASA Ames Center for Nanotechnology)

tion the nanocomputers gather. He sees applications appearing as early as two years out.

Diagnosis also benefits such fields as agriculture. Northwestern's Dravid sees this application arriving in the next three to five years. Nanosensors could be used to monitor the health of crops and livestock.

"To be able to diagnose a threat ahead of time requires that you have tools and techniques to detect single molecule antigens," says Dravid. Diagnostics and sensing is clearly an area where nanotechnology will have one of the first and most immediate impacts, according to Dravid.

Wherever nanotechnology appears in relationship to data, the need to gather and process that data exists. Pervasive computing at the nanotech level will fill much of that need. P

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