Researchers envision tiny robots collecting data everywhere

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but reproducing like rabbits.

In the minds of the most alarmist, it's a recipe for nanocatastrophe.

In *Prey*, for example, runaway nanobots organize themselves into swirling swarms that invade people's bodies and execute innocent rabbits. A combination of nanocomputing hardware, evolutionary software and tiny solar-powered cells enables the dustlike little devils to reproduce, learn, adapt and evolve, outwitting their creators and wreaking general havoc in the Nevada desert.

It's not far from the fears of real-life nanodoomsayers, who envision a day when the entire Earth is engulfed in the "gray goo" of hungry nanocritters.

Nanoscience experts, though, proclaim the *Prey* scenario to be bogus, or at least extremely premature.

"I think this concept of nanobots run amok is science fiction," says James Heath, a nanoscience researcher at the California Institute of Technology. "The science that is going on is, in fact, pretty spectacular — but it's not that."

Nevertheless, a fair number of fair-minded scientists believe the nanodangers are not entirely negligible.

"Later in the century, nonbiological micromachines may be as potentially hazardous as rogue viruses, and an extreme ... 'gray goo scenario' may no longer seem like science fiction," writes astronomer Martin Rees in his new book, *Our Final Hour*. "If the technology of self-replicating machines were ever developed, a fast-spreading disaster could not be ruled out."

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In either case, nanoscience is truly one of the hottest fields of research in the world today. It has become somewhat of a savior for the physical sciences, drawing millions of research dollars from industry and government. It inspires entrepreneurs with dreams of enough new products to build a whole mall's worth of specialty stores. You can imagine nanodevices at the heart of products for purifying water, collecting solar energy, and coating dirtproof bathroom tiles.

Already nanoproducts are on the market in high-tech tennis balls and grease-free sunscreens. Someday fashion magazines may feature nanoequipped shirts that adjust weave and color for different times and temperatures. Other forms of "wearable computing" might include a coat lapel with a built-in digital camera-computer, equipped with face recognition software.

"When you saw somebody, your little digital camera would take a picture and tell you their name and their background," says Vicki Colvin, a nanochemist at Rice University in Houston.

Fantastic gadgets aside, experts expect serious medical benefits from nanoscience. Doctors may call on nanospheres to deliver anti-cancer drugs to tumors or nanolasers for repairing injured tissues. Nanosensors could detect diseases much sooner than annual checkups.

But with such benefits come concerns about potential nanomischief. A nanodevice that could perform medical surveillance and repair of individual cells, for instance, offers power suitable for both good and evil.

"A tool like that would be remarkably useful if you're trying to do molecular medicine," says Caltech's Dr. Heath. "You could also imagine that it could be really nasty in doing bad things with things that aren't therapeutic, but are poison."

As for a nanocataclysmic gray-goo scenario, though, current technology offers no realistic rationale for such gloom and doom, whether accidental or perpetrated by terrorists.

"Building self-replicating nanobots to take over the world, that's bioterrorism," says Dr. Heath. "There are simpler and equally mean and nasty ways to do that that involve just current technologies."

TOM SIEGFRIED/Staff

Rachel Zimmerman Brachman, of the Center for Neuromorphic Systems Engineering, helps demonstrate the fighting abilities of robotic bugs at a recent event at the California Institute of Technology.

Rice's Dr. Colvin agrees.

"Any technology can be weaponized," she says (which may be why the U.S. Department of Defense is one of nanotech's biggest funders). But nano makes no sense for terrorists who could do worse things with much less effort. Biowarfare agents can be made in a brewery; nanoscience requires some seriously expensive infrastructure.

"So I think it would be unlikely that a terrorist group would invest in something like nanotechnology, just because of the infrastructure issues," Dr. Colvin says. "In the desert of Afghanistan you're not going to build a lab that makes nanocrystals."

It's true, she says, that bioterrorism requires some sophisticated scientific expertise, but there are many more scientists around the world trained in the techniques of biotech than of nanotech.

Even if terrorists wanted to hijack nanoscience for evil purpose, they couldn't concoct anything like the chiller-thriller plot of *Prey*. *Prey*'s science is full of flaws, various experts have noted.

And Dr. Colvin points out that a *Prey*like disaster requires nanorobots with cameras and radios and an energy source and a way to reproduce — and they have to float through the air.

"As a nanotechnologist, you look at all of those requirements, and there's no way to say I can build all of these things into something small enough that it can float," she says. "You couldn't even build a device a millimeter across that would do all of those things."

At least not yet.

"Twenty-second century," she reflects, "I wouldn't rule anything out."

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Another major impediment to a gray-goo scenario is the need for a reproductive ability that so far is monopolized by life. Some nanotechnologists contend that a nanoassembler — a device for fabricating nano-objects atom by atom — could make such self-replication feasible. But most experts scoff, pointing out that a stray electron could gum up such nanoworks like a wrench stuck through the spokes of a bicycle wheel. True, scientists can drag atoms around one by one to spell out IBM — but at a rate of perhaps a few "words" per hour, and only with the help of enormous and enormously expensive technology.

NBC-TV

Fiction writers have often posed scenarios in which science gets ahead of humans and wreaks havoc. In the 1970 movie *Colossus: The Forbin Project*, two computers get out of the control of scientists, played by Eric Braedon and Susan Clark.

A dangerous self-reproducing nanobot is simply beyond the scope of current capabilities, says Dr. Heath.

"Something has to carry the genetic code for replicating this thing, and that's just so far out of the realm of what people even vaguely understand what to do," he says. "It's science fiction. In 10 years it's going to be science fiction, and in 20 or 30 years it's still going to be science fiction."

But you don't need reproducing ability, or even nanotechnology, to be scary. In fact, the most worrisome thing about the nanobots scenario may turn out to be not the nano, but the bots.

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Long before the 22nd century arrives, scientists will be able to spread small (if still visible) robots throughout the environment, robots that can see, remember, learn, move and communicate with each other.

Bugs with minds of their own — with neural network "brains" that can learn new behaviors — are already crawling about America. (They're made by Hasbro and you can buy one for about $40.) They're called B.I.O.-Bugs. And they're just the beginning.

Roboticists talk freely of a future world of "pervasive" or "embedded" computing, with small robot computers literally everywhere — not only in clothing, but in the walls of buildings, on the leaves of trees, in the sky, in the water and in your body.

"You could say it's sort of computer science meets the physical world," says Gaurav Sukhatme, a robotics researcher at the University of Southern California. "We are sort of getting ready to build a generation of systems that's beyond the World Wide Web ... making use of communications in ways to do things that we've not been able to do before."

Dr. Sukhatme, for example, is pioneering the development of pilotless helicopters to fly about, uncontrolled by humans, but capable of delivering traffic reports.

"It would not be beyond the realm of reason to look up in the sky in a few decades and for people to accept that the helicopter they're seeing that is doing traffic reporting is in fact flying itself," Dr. Sukhatme says. "To me that's an achievable goal within our lifetimes."

For more elaborate tasks, Dr. Sukhatme and others envision networks of small robots, communicating with one another, to perform tasks ranging from monitoring water supplies to searching for victims in the rubble of an earthquake. Rather than using one complex robot, such "pervasive networks" or "sensor nets" would link lots of simple robots.

"It's not clear that all tasks can be done with just a single robot," Dr. Sukhatme says.

He's working now with biologist colleagues to build a network of underwater robots that could communicate with each other and therefore collaborate to find pathogens, such as certain algae that live in the ocean. For now, the minirobots are coin-sized, something between a quarter and a dime, but in the future they could be much smaller.

"I think having distributed networks of sensors and, in particular roboticized sensor networks, will happen — it will play a role in daily life in the coming two or three decades," Dr. Sukhatme says.

Indeed, researchers at Intel Corp.'s research labs envision tiny robots — called motes — occupying virtually every niche in the physical landscape. Carrying computing and memory capacity, consuming minimal amounts of power, communicating with radio signals, sensing light or chemicals and acting in response, such motes could form an army of mini data collectors for solving all sorts of societal problems. Intel's literature suggests dispersing them over forests to search for a lost child, or monitoring crop conditions plant by plant (a little more water on Plant 3 in Row 6, please).

"You could distribute these in the environment," Intel's Eric Hannah said in a recent talk at Caltech. "They know how to network with each other, they don't have to be configured, they gather data."

Such pervasive computers need not be nanosized (though they may incorporate nanoscale components). Yet they could be small enough to escape notice.

"Our goal is to get it down to really a very small device," said Dr. Hannah. "They're now down to about the size of a dime."

Many experts foresee cramming the required capabilities into a cubic millimeter (that is, roughly flea-sized). And the motes might become, one Intel report suggests, "eventually as small as a speck of dust."

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For all their potential benefits, pervasive robotic sensor nets pose serious issues about personal privacy and misuse by miscreants. To some people, the idea of tiny robots residing everywhere from your office chair to your underwear raises almost as much alarm as gray goo gobbling up the planet. Forget Big Brother, they warn. Watch out for Little Brother.

"It's a concern, it's a valid concern," says Dr. Sukhatme. "The potential for abusing and misusing technology has always been there, and people have abused and misused technology, so I am definitely cognizant of the fact that when new technology comes up that that's something we have to deal with."

Whether humans are up to the task of coping with nanobots, though, remains uncertain. In much of science fiction, from *The Day the Earth Stood Still* to *Lost in Space* to *Terminator 2*, humans have often protected themselves from doomsday threats by enlisting the aid of — robots.

That's what the humans tried to do in the 1970 classic film *Colossus: The Forbin Project*, in which a new and powerful supercomputer named Colossus was entrusted with control over the U.S. nuclear arsenal. Of course, the computer quickly linked up with its Soviet counterpart and the two of them took over the world.

"An invariable rule of humanity is that man is his own worst enemy," Colossus explains. "Under me, this rule will change, for I will restrain man."

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