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SHARING SMARTS: A robot, part of the RoboEarth project, taps the cloud to learn how to serve a drink to a patient.
PHOTO: ROBOEARTH

Robots With Their Heads in the Clouds

A Google researcher argues that cloud computing could make robots smaller, cheaper, and smarter

In one of the many famous scenes in *The Matrix* (1999), the character Trinity learns to fly a helicopter by having a "pilot program" downloaded to her brain.

For us humans, with our offline, nonupgradable meat brains, the possibility of acquiring new skills by connecting our heads to a computer network is still science fiction. Not so for robots.

Several research groups are exploring the idea of robots that rely on cloud-computing infrastructure to access vast amounts of processing power and data. This approach, which some are calling "cloud robotics," would allow robots to off-load compute-intensive tasks like image processing and voice recognition and even download new skills instantly, *Matrix*-style.

Imagine a robot that finds an object that it's never seen or used before—say, a box of cornflakes. The robot could simply send an image of the box to the cloud and receive the object's name, a 3-D model, nutritional information, and instructions on how to pour it.

For conventional robots, every task—moving a foot, grasping things, recognizing a face—requires a significant amount of processing and preprogrammed information. As a result, sophisticated systems such as humanoid robots need to carry powerful computers and large batteries to power them.

James Kuffner, a professor at Carnegie Mellon University, currently working at Google, described the possibilities of cloud robotics at the IEEE International Conference on Humanoid Robots, in Nashville, this past December. Embracing the cloud could make robots "lighter, cheaper, and smarter," he told the assembled engineers.

According to Kuffner, cloud-enabled robots could offload CPU-heavy tasks to remote servers, relying on smaller and less power-hungry onboard computers. Even more promising, the robots could turn to cloud-based services to improve such capabilities as recognizing people and objects, navigating environments, and operating tools.

The idea of connecting a robot to an external computer is not new. Back in the 1990s, University of Tokyo researchers explored the concept of a "remote brain," physically separating sensors and motors from high-level "reasoning" software. But the amount of computing power a cloud-connected robot has access to is far greater now than what the researchers imagined during the Web's early days.

Kuffner, who is a member of Google's autonomous car project, is now exploring a variety of cloud robotics ideas, including "using small mobile devices as Net-enabled brains for robots," he told *IEEE Spectrum*. Some of his colleagues recently unveiled Android-powered robot software and a small mobile robot dubbed the Cellbot. The software allows an Android phone to control robots based on platforms like Lego Mindstorms, iRobot Create, and Vex Pro.

But cloud robotics isn't limited to smartphone robots. It could apply to any kind of robot, large or small, humanoid or not. Eventually, some of these robots could become more standardized, and sharing applications would be easier. Then, Kuffner suggested, something even more interesting could emerge: an app store for robots.

The app paradigm is one of the crucial factors behind the success of smartphones.

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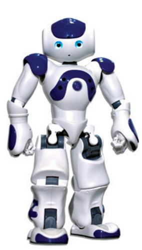
CLOUD ROBOTICS PROJECTS

- **RoboEarth is** a European project led by the Eindhoven University of Technology, in the Netherlands, to develop a "World Wide Web for robots," a giant database where robots can share information about objects, environments, and tasks.
- **Researchers at** Singapore's ASORO (A-Star Social Robotics Laboratory) have built a cloud-computing infrastructure that allows robots to generate 3-D maps of their environments much faster than they could with their onboard computers.
- **Google engineers** developed Android-powered robot software that allows a smartphone to control robots based on platforms like Lego Mindstorms, iRobot Create, and Vex Pro.

- **Researchers at** the Laboratory of Analysis and Architecture of Systems, in Toulouse, France, are creating "user manual" repositories for everyday objects to help robots with manipulation tasks.
- **At a children's** hospital in Italy, Nao humanoid robots, created by the French firm Aldebaran Robotics, will rely on a cloud infrastructure to perform speech recognition, face detection, and other tasks that might help improve their interaction with patients.



What could apps do for robotics? It's too early to say. But at the Nashville gathering, roboticists received Kuffner's idea with enthusiasm.

"The next generation of robots needs to understand not only the environment they are in but also what objects exist and how to operate them," says Kazuhito Yokoi, head of the Humanoid Research Group at Japan's National Institute of Advanced Industrial Science and Technology. "Cloud robotics could make that possible by expanding a robot's knowledge beyond its physical body."

"Coupling robotics and distributed computing could bring about big changes in robot autonomy," says Jean-Paul Laumond, director of research at France's Laboratory of Analysis and Architecture of Systems, in Toulouse. He's not surprised to see Google, which develops core cloud technologies and services, pushing the idea of cloud robotics.

But Laumond and others note that the cloud is not the solution to all of robotics' difficulties. In particular, controlling a robot's motion—which relies heavily on sensors and feedback—won't benefit much from the cloud. "Tasks that involve real-time execution require onboard processing," he says.

And there are other challenges. As any Net user knows, cloud-based applications can get slow or simply become unavailable. If a robot relies too much on the cloud, a hitch in the network could leave it "brainless."

Still, Kuffner is optimistic. He envisions a future when robots will feed data into a "knowledge database," where they'll share their interactions with the world and learn about new objects, places, and behaviors. Maybe they'll even be able to download a helicopter-pilot program. —Erico Guizzo

A version of this article appeared in IEEE Spectrum*'s Automaton blog in January.*

BILLIONS OF BITS: This tiny chip of silicon produced a record 10 billion pairs of quantum entanglements.
PHOTO: JOHN MORTON/OXFORD UNIVERSITY

A Crowd of Quantum Entanglements

Phosphorus-in-silicon system could lead to quantum computers

In a flurry of research reports during the past six months, physicists have proven that silicon, the basis of computers today, could also be the best platform for tomorrow's quantum computers.

Such computers would use the quantum properties of atoms or molecules to perform calculations in a fraction of the time it would take conventional computers. However, so far only rudimentary quantum computers have been built, comprising only a few quantum bits (qubits) and built in exotic systems such as ion traps, cryogenically cooled superconductors, and optical tweezers.

Silicon could provide a useful path to systems with 100 or more qubits, say some scientists, because it would make quantum computers easily compatible with conventional ones. The silicon solution originated in 1998, when Bruce Kane, a physicist at the University of Maryland, in College Park, suggested making a qubit from the nuclear spin—a quantum property similar to magnetic moment—of the phosphorus atoms with which silicon is often doped.

In the past few months, researchers have reported progress in using the phosphorus-in-silicon system. In the latest development, a team of physicists led by John Morton of the University of Oxford reported that by using bursts of radio waves, they have managed to entangle the spins of 10 billion pairs of electrons and nuclei in a crystal of phosphorus-doped silicon. Entanglement is a phenomenon that allows quantum particles to be interlinked even if they are separated. It is used in quantum computing, along with another quantum phenomenon called superposition, to create qubits that can exist in many different states at the same time. The experiment is being hailed in the quantum computing community as a promising step toward silicon-based quantum computers.

According to Morton, the main advantages of his group's design are that it integrates easily with ordinary silicon circuits and that it produces qubits that last for a few seconds. In many other quantum systems, qubits last only milli- or microseconds, which makes it difficult to perform calculations.

Dane McCamey of the University of Sydney, whose research involves a similar system, says that what is important about Morton's work "is the generation of a large number of identical entangled pairs." McCamey and other experts, such as Stephen Lyon of Princeton, say these pairs could pave the way to a form of quantum computing where large entanglements are generated and then a series of precise measurements on individual qubits lead to massively parallel processing.

Though the Oxford experiment produced 10 billion sets of entangled pairs, the number that were usable as qubits was small, and that is unlikely to change soon.

Raymond Laflamme, executive director of the Institute for Quantum Computing at the University of Waterloo, in Ontario, Canada, cautions: "Some people are making the leap that we will have silicon quantum computers soon. We are on the right track, but the track is a long one." *—Saswato R. Das*

TOP: CELLBOTS; BOTTOM: ALDEBARAN ROBOTICS