The Bionic Man

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When I hear the phrase "human-implantable electronics," I must confess that I feel a bit queasy. It conjures up a more extreme image of pervasive computing than is usually justified. However, my perspective is that of a relatively healthy person in his 40s, without any physical handicaps. If my hearing was impaired or my heartbeat arrhythmic, I might be keen to find a remedy—and, at this time, an electronic implant would probably be the way to go. Putting my emotional reaction aside, when I think about the possibilities of implantable technology, it actually begins to sound pretty cool.

STILL SCIENCE FICTION

In the '70s, I often watched the *Six Million Dollar Man*, a popular TV series based on Martin Caidin's science fiction novel *Cyborg*. Many of you might not have seen this old show (although now airing is an updated version of the spin-off, *The Bionic Woman*). The storyline centers on an astronaut and test pilot who loses both of his legs, an arm, and one eye in a plane crash. A top-secret government organization is tasked with rebuilding him using the best technology available, including nuclear batteries, high-resolution cameras, and electronic actuation for muscles, all in natural-looking prosthetic forms. The organization succeeds, running up a bill of six million dollars. The kicker to the story is that he wasn't just rebuilt; he became better, stronger, and faster than any ordinary person, leading to

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many exciting adventures on behalf of the US government.

The prospect of advanced implantable devices replacing body components and performing better than nature is intriguing. However, we're a long way from this vision—even if we had six million dollars to spend. It's usually hard to improve on nature and to create solutions that are both functional and durable, standing the test of time.

For real-world use, the latter is a challenging requirement. We currently build implants from inorganic materials, and as such, implants can't repair themselves when they become worn out or damaged, so we must design them to withstand decades of stress. Given that the average lifespan in the western world is 80 years or so, an implant installed in our youth might need to last 70 years. There aren't many things we can build that last even close to that.

Future technology will likely improve dramatically, so replacements and upgrades will be a necessary part of the implantation process. For electronic devices embedded in our bodies, this means periodic surgery, which doesn't represent a convenient, one-time fix for the problem the device was designed to solve.

CONSIDERING TRADE-OFFS

In addition to implants that support failing bodily functions, we're beginning to see more controversial implantable technologies, such as Verichip's human RFID tag. The tag, encapsulated in a small rugged glass vial the size of a grain of rice, is injected under the skin. It has wide application, from tagging children in case they're abducted or lost, to helping Alzheimer's patients who might wander off, putting themselves at risk.

More recently VeriChip produced VeriMed, and in April 2002, the FDA approved its use. This implantable tag has a unique identity code that is

used as an index into a medical database, providing rapid access to medical records, treatment histories, medication regimes, and known allergies. The advantage is associating medical information with a person so that emergency medical staff can easily access it—even if the person is unconscious. Furthermore, unlike a bracelet, you can't easily separate it from a person's body, making it more likely to survive an emergency situation.

There are disadvantages, of course, such as the risk of privacy violation or of the implanted materials causing medical complications. As with most things in life, we need to consider the cost-benefit trade-off.

RESEARCH LAYS THE GROUNDWORK

Some researchers have begun to experiment with implantable RFID as a means to control and interact with the environment. The best known example is Kevin Warwick, professor of cybernetics at the University of Reading, UK. In February 2000, *Wired* ran an article ("Cyborg 1.0") about his experiment in which he inserted an RFID tag under the skin of his arm. The tag let him control electronic door locks (the ultimate access control), lights, and other equipment nearby. He later took this idea to the next level, using a subdermal chip with 100 electrodes to make a direct connection to his median nerve. By electronically interpreting the recorded signals, he could remotely control a robotic arm through the Internet at another site in the university.

Researchers at Brown University extended this concept by demonstrating that an implant in a Rhesus mon-key's brain could control the position of a computer's cursor. Philip Kennedy, a neurologist and founder of Neural Signals Inc., has similarly demonstrated this approach in humans. He found that disabled people, using implants, could control a computer cursor with their thoughts and type words on a graphic representation of a keyboard, with a typing speed of about three words per minute. Although these are early results, they show that direct neural implants are tractable and will one day provide a routine treatment for severely disabled people—a worthy goal for these experiments.

As part of the effort to overcome deafness and restore sight, research also proceeds on implants that send information directly into our nervous system. One approach to vision restoration has been to directly stimulate neurons in the visual cortex in response to an image captured by an electronic camera. Researchers have conducted crude versions of these experiments since 1978. However, a significant milestone came in 2002 when biomedical researcher William Dobelle partially restored sight to Jens Naumann, blinded in adulthood. With this treatment, Naumann achieved basic obstacle avoidance and navigation.

BEWARE OF THE BORG?

Between these two approaches, it's clear that implants open up the potential for two-way communication between our neurons and computational components. This leads us to speculate whether we can create electronic extensions to our brains, building additional neural networks and storage modules to augment our brain

functions. In combination with digital communication networks, networking neural functions between people might be possible.

We don't yet know how to do this, but it makes me wonder. What are the technical limits, if any? Could this lead to direct wireless communication so that some day I'll be able to share my thoughts with another person? As we move beyond prosthetic implants to deliberate human augmentation, this research will certainly trigger debate on what's ethical practice in this area. Linking our brains directly with a computing infrastructure, or using the infrastructure to directly influence our thoughts, might be going too far.

I began this article talking about an inspiring TV show that depicted a bionic man with superior capabilities, but the latter discussion reminds me of another show depicting a race of people living a far-from-desirable life. On the assumption that many of you are fans of *Star Trek: The Next Generation*, you'll remember the archenemy, the Borg. These beings were augmented by implants wirelessly linking them together in a network they called "the collective." They aimed to assimilate all other races with their technology, adding to their own capabilities in the process. Not an image I want to leave you with today!

Pervasive computing is about embedding computation in the world around us to make its use implicit and for it to naturally fit our work practices. Mark Weiser said it even better, "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." Implantable technology takes this notion to the next logical step, enabling us to become part of the computational infrastructure and indistinguishable from it. You can argue that this actually subsumes pervasive computing's goals.

Although this all sounds like science fiction now, we're laying the groundwork for what will one day be a radical new relationship between man, computation, and the world. However, in this special issue, we present a far more grounded view of current research into implantable technology. P