Out in a Limb
Natural exoskeletons abound, wreak havoc on their enemies with missiles and hydrogen bombs. To Heinlein, familiar from science fiction and comic books, the beauty of a powered suit is that you just wear it and it takes orders directly from your muscles.

Four years after Heinlein's book came out, Marvel Comics introduced the character Iron Man, a rich industrialist encased in a homemade iron exoskeleton that enables him to lift tons at a time, fire deadly radiation beams, and even fly. In the 1986 film Aliens, Sigourney Weaver as Lt. Ripley straps herself into an industrial loader-like a forklift with legs—to battle the hideous, mucus-covered alien queen. Actual efforts to make motorized exoskeletons date back to the 1960s, although design studies began well before. Hollywood's human-cum-forklift idea may have arisen from a 1965 project at the General Electric (GE) Research and Development Center in Schenectady, N.Y. There, a design for a self-standing exoskeleton powered by hydraulics and electricity came to life as a hulking contraption called Hardiman 1.

The robot, as heavy as a car, would have enabled a person to lift a refrigerator as though it were a bag of potatoes. However, the machine's inventors could only get one arm of the device to work. And attempts to operate both legs at once would lead to "violent and uncontrollable motion," according to an old GE report on the project.

Since then, most development has focused on components for exoskeletons rather than complete systems. For instance, before Kazerooni and his colleagues built their new exoskeleton, they had devised a number of so-called extenders, such as force-amplifying arms.

Even the new exoskeleton is not a full-body device. It's only a "lower extremity enhancer," known by the acronym Lee, the researchers say. The device has attracted DARPA's eye, but the Berkeley group created the machine during the past 6 years with funding from nonmilitary sources.

At the University of Utah in Salt Lake City and the nearby spin-off company Sarcos, a team led by Stephen C. Jacobsen has been creating so-called master-slave telerobotic devices. They include a slave limb that follows the motions of a person's arm that's yoked into a master arm across the room.

Although this type of technology has been around for decades, used for instance, to handle radioactive materials, the latest versions are more responsive and dexterous than past device. A full-body suit that Sarcos developed implements the same idea on a larger scale. Whatever the wearer of the sensor-equipped harness is doing—from calm sitting to wild dancing—a humanoid robot would instantly do the same thing.

Researchers at Oak Ridge (Tenn.) National Laboratory have developed a lifting machine that can amplify hand motions enough to manipulate tremendous loads with the precision of a jeweler—a difficult combination to achieve. The experimental device, developed for loading weapons into aircraft, can sustain jolts without getting jitters that often crop up when a control system is suddenly disturbed, says Francois Pin, one of the machine's inventors. The lifter enables its operator to raise a 2,200 kilogram bomb as if it weighed only 4 kg.

Looking at these and other developments in exoskeleton-related technology, Garcia believes that "all this combined together makes this a good time" to try again for the complete package. "We're going to take some of these technologies that are almost ready... and push them over the edge," he says.

The result may be some formidable...
The leap from today's technology to an exoskeleton meeting Garcia's goals is a huge one. Among the three DARPA contractors working on exoskeletons for ground troops—Kazerooni's lab, Jacobson's operation at Sarcos, and Oak Ridge's robotics group—only Kazerooni's team has actually demonstrated a powered exoskeleton.

Millennium Jet in Sunnyvale, Calif., which is also receiving DARPA funds, is under way with developing a personal flying machine known as Solo Trek XPF (see sidebar). The vehicle is a one-person device but not a wearable exoskeleton.

To build a system in which a robot shadows every move a person makes is a complex undertaking. After detecting the motion and gauging its speed and force, the robot must translate those readings into a parallel motion by some of its components. All the while, other exoskeleton components have to be off by much to cause the wearer discomfort or fatigue, says Jacobsen. Yet if a man wears even a crude device that can pull its own weight provides the Berkeley team with an important confirmation. "It verified some of our control theories, which shows we are going in the right direction," Kazerooni says.

Even as the research teams work out the early details of their exoskeleton designs, some of the investigators are looking beyond this round of experimentation. "The LEAP program is a huge one. "It involves many of the key issues that we are looking at in the LEAP program," Jacobsen says. Other researchers are building exoskeletons that are "invasive"—not just worn but partially implanted within a person's musculature and nervous system.

Jacobsen says he's thinking in the opposite direction—about putting more human nature into the machines. His idea is to build an exoskeleton intelligent enough to take care of the soldier wearing it. If the human trooper is badly wounded, the machine would say to itself, in effect, "Take this guy home."