

[BUSINESSWEEK ONLINE : AUGUST 7, 2000 ISSUE](#)

SPECIAL REPORT

Thinking Machines

After years of hype and letdowns, computers are starting to acquire real factory smarts

The trouble with engineers, says Andrew J. Keane, a mechanical engineer at Britain's University of Southampton, "is that we are trained to think with regular geometry--straight lines, circles, and 45-degree angles. But take a look at nature. How many bones in the human body have straight edges?"

Answer: none. And when it comes to manufacturing, it pays to take a cue from Mother Nature. That's why Keane has joined a growing band of evangelists for so-called evolutionary computation. This refers to a potful of biologically inspired techniques for creating new products, more efficient factories, and better business processes.

What you are really looking at, though, is artificial intelligence dressed up in fancy new garb. Many researchers would rather not mention AI. It conjures up shattered dreams of machines as smart as people. But AI is back, with all its mysterious and nonlinear edges. And it is delivering impressive results in manufacturing. "AI was really overhyped 15 years ago," notes William S. Mark, vice-president for computer science at SRI International, Silicon Valley's venerable think tank. Some of the early pioneers disappeared, he says, "but not the technology. It's far better than ever, and more prevalent."

QUICK STUDY. In fact, peek under the wraps of new software tools for manufacturing, and you'll often find AI, probably sporting some other name. At Honeywell International Inc.(HON), a leading maker of factory control systems, it's called automated reasoning. Industry watcher AMR Research Inc. in Boston estimates that up to 40% of all new manufacturing-related software now incorporates some form of AI.

Unlike traditional AI, which tried to imbue computers with top-down intelligence, the new approaches let systems develop their own smarts, from the bottom up. The field has some colorful characters, such as intelligent agents, brain-like neural networks, and Darwinian genetic algorithms (Table). Sometimes, evolutionary techniques can find answers that elude conventional problem-solving methods. General Electric Co.'s (GE) energy-efficient halogen light bulb is a good example (page 80). Other times, the new software can generate startling results that open the eyes of engineers.

Southampton's Keane, for example, used a genetic algorithm to design a support arm on satellites, called a truss. It produced a novel shape that human engineers might never consider (page 84). "When we found what the final designs looked like, we rethought how these things work, and now we see the logic," says Keane. The main goal he set: prevent vibrations from being transmitted along the truss so ultrasensitive instruments mounted at the far end would not be affected by vibrations from, say, the satellite's navigational rockets. The software discovered on its own that by changing the angles at every joint between crossbars and edge beams, vibrations could be progressively reduced to next to nothing.

While AI technology has made substantial progress, everything isn't hunky-dory yet (page 86). For example, engineers complain that they have trouble using some of the genetic tools aimed at optimizing manufacturing processes. One hitch with them is that the number of calculations required increases geometrically with each additional variable. Finding the best combination of just six variables would require analyzing 720 possible combinations. But with 12 variables, the possibilities explode to 479 million. Industrial problems may involve scores of variables, so even supercomputers can chug away

for days, weeks, or years before coming up with the optimum answer.

The aerospace industry is notorious for the complexity of its optimization puzzles. Only recently has it become feasible to refine a plane's design by repetitively simulating the air flowing around an entire airframe. Before, that took so long it was done just as a final check. And at least a month was needed even for many a seemingly simple jobs, like simulating the firing of the braking jets on the Space Shuttle as it comes in to dock with the Space Station, says John Jian Dong, head of multidisciplinary optimization at Boeing Co.'s [\(BA\)](#) Reusable Space Systems unit.

But evolutionary computing has some magic up its sleeve. Because the weak solutions from each generation aren't permitted to procreate, not every possible combination gets evaluated. So the problem shrinks dramatically, as does the execution time. Now, Dong gets his Shuttle-braking optimizations back in a couple of days.

Of course, as the technology grows more powerful, expectations rise, and people like Ren-Jye Yang end up feeling impatient. He's a Ford Motor Co. engineer who uses optimization to hunt for ways to improve vehicle safety, and his computer models of crash tests generally have 10 to 20 variables. Yang says each simulation takes an hour on a Cray supercomputer or a week on a high-end computer from Silicon Graphics Inc. [\(SGI\)](#)--"and we have to run 40 simulations to get each optimization."

Even after all that, the result probably won't be the theoretical optimum. "There are no algorithms that can guarantee you'll find the one global optimum," says Boeing's Dong. "So in industry, optimum just means a much better solution."

In any case, finding the one absolute best solution might not be so great, says Lawrence J. Fogel, president of Natural Selection Inc. in La Jolla, Calif. "It might turn out to have unforeseen side effects that you didn't count on, or be too expensive--and then you'd have to run the whole problem again," he says. "So what you want are the best few."

FAMILY AFFAIR. Fogel is a pioneer of evolutionary computing. He began publishing his ideas in scientific journals in the early 1960s. But his theories went largely ignored until 1992, when they were revived and embellished by his son, David B. Fogel, chief scientist of Natural Selection. That same year, a similar technique, called genetic programming, was unveiled by John R. Koza, a researcher at Stanford University.

Koza insists that evolutionary methods will soon evolve into systems that discover new ideas and inventions. In fact, he has compiled a list of two dozen examples of where genetic programs already have created algorithms and products that match or improve on inventions covered by existing patents. And in two instances, the results of evolutionary computing were actually awarded a patent: an antenna (U.S. Patent 5,719,794) and an unusually shaped airplane wing (D0363696). This facility of genetic design really shouldn't be surprising, Koza says: "Evolution proves how good it is at design all around us."

Maybe. But that doesn't mean people will cotton to the situation. Two years ago, for example, when software giant Computer Associates International Inc. [\(CA\)](#) came up with Neugents, a hybrid neural network and intelligent agent, one of the first applications was to stand guard over CA's worldwide computer network. The Neugents monitor 1,200 data points every five seconds, looking for patterns in the data that coincide with events that led to past computer crashes. "The software can predict when the system is likely to crash within the next 45 minutes," says Gary E. Layton, marketing vice-president for interBiz Solutions, a new division of CA. "But the guys here didn't believe this kind of thing could work, so they ignored the first warning. Sure enough, the system crashed, just like the software said it

would."

RAINMAKER. CA has bigger plans for the technology, however--along the lines of Koza's invention machine. With BizWorks, a new software suite marketed by interBiz, "we're trying to apply this predictive capability to business opportunities, not just warnings of failure," says Layton. "We want the software to sift through large volumes of data and find proactive positives--opportunities that we would probably spot later on down the road, but not for a while."

To make tons of money, however, you don't need to probe the actual future, says Steven A. Chien, technical supervisor of the AI group at NASA's Jet Propulsion Laboratory in Pasadena, Calif.: "If you're operating your business on data that's only five days old, but all your competitors are using 30-day-old data, you're effectively predicting the future as far as they are concerned."

Chien's specialty is automated planning and scheduling to maximize return on NASA's investments in space facilities and the logistics maze that surrounds a blast-off. But the principles also apply to manufacturers, especially build-to-order companies such as Dell Computer Corp. ([DELL](#)). "Just bringing together all the different parts and materials you need to fill thousands of orders isn't that hard," says Chien. "What's hard is minimizing your inventory costs."

That's the problem at the root of the explosion in shop-floor scheduling systems and supply-chain management tools. A flock of vendors already offer manufacturing execution systems and enterprise resource planning (ERP) software--Aspen Technology, Camstar, Datasweep, i2 Technologies ([ITWO](#)), Manugistics ([MANU](#)), Oracle ([ORCL](#)), and Wonderware, to name just a few. This represents just the tip of a brewing supply-chain revolution, says NASA's Chien. Soon, even tiny job shops will be exploiting the new capabilities. "It'll be like computerized payroll systems," he says. "At first, only big companies were able to buy them. Now, they're in every small business."

In addition, as managers get comfortable with evolutionary computation, these programs will gradually become just another everyday technique for analyzing options and improving individual factory operations. At Sandia National Laboratories, researcher Leslie D. Cumiford took two years to develop a software agent for controlling a brazing oven, which is used to solder ceramic parts to metal parts at high temperatures. That's a big-time investment, but Cumiford was breaking new ground. As computers gain more horsepower and the software improves, manufacturers will routinely run genetic programs to help make return-on-investment decisions--not just on major projects such as building a new factory but also on the merits of individual products. Production lines will be continually analyzed to improve flexibility and trim product change-over times.

Not far down the road, manufacturing will become totally digitized and thus more amenable to evolutionary techniques. Israel's Tecnomatix Technologies Ltd. ([TCNO](#)), for one, has software that captures a detailed computer model of an entire factory. And supply-chain management and ERP suppliers are starting to revamp their software into smart modules, or so-called object-oriented components, that talk to each other. "At the plant level, a lot of devices now showing up have embedded Web servers," says Kevin E. Prouty, research director of AMR Research. They can relay shop-floor data to any computer with a Net connection. "Now, you have access to information that people once only dreamed of."

Ultimately, predict the seers, every piece of factory equipment will have intelligent agents hovering within. Most office operations will also have associated software agents, from sales and purchasing to customer service and shipping. All of these agents will jabber among themselves to evolve production and delivery schedules. Almost every AI lab and manufacturing research center is working toward this multiagent future. AMR's Prouty probably speaks for many factory engineers when he proclaims:

"Nirvana is coming."

By OTIS PORT

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