Forefront

RESEARCH & GIVING COLLEGE OF ENGINEERING UNIVERSITY OF CALIFORNIA, BERKELEY 1997

FEATURING THE **BERKELEY ENGINEERING FUND ANNUAL REPORT**

BERKELEY RESEARCH HIGHLIGHTS

Seeing the art in algorithms

FROM MINING TO MANUFACTURING, ALL SORTS OF PROBLEMS CAN BE UNRAVELED WITH MATHEMATICAL WIZARDRY

SOME HAVE CALLED THE mathematical craft used to develop algorithms — sets of rules that define problems within a finite number of steps — more than raw expertise. They have called it art. Like a world-renowned symphony, a significant algorithm may take years to refine. Once complete, an algorithm's performance is judged in part on its efficiency and speed in solving problems. But beyond that, those especially well versed in the algorithmic arts judge its performance in much the same way a newly written symphony is reviewed — they assess its fundamental elegance and integrity.

"Developing algorithms is not just a technical creation," says Berkeley industrial engineering faculty member Dorit Hochbaum. "There's an art to getting from the messy, real-world problem to a clear-cut model that captures the problem's most important aspects."

Hochbaum develops algorithms that can be used to solve a wide array of real-world problems — electronic circuit testing, site placement for a city's emergency facilities, routing problems in factories, scheduling for semiconductor manufacturing processes, logging management to preserve habitat, or even taxonomic classification for biologists.

The example most often used to illustrate how algorithms work is called the traveling salesman problem, which begins with a lone salesman who must visit a specified number of cities within a specified time. The dilemma is finding the most efficient and cost-effective route.

If you begin with just eight cities, says Hochbaum, there are less than 1,000 possibilities. But once you extrapolate to 70 cities, a more realistic scenario for today's mega-corporations, and factor in the cost of travel and lodging, the number of possibilities are staggering.

"It's more than the number of molecules in the universe," says Hochbaum. This sort of problem is called "intractable." In theory, it's solvable, but by the time a solution is found, so much time has elapsed the solution is rendered useless.

"Even in the early 1970s, it was almost impossible to solve the traveling salesman problem using 60 or 70 cities," says Hochbaum. "But now we can, and the number of cities for which we can solve the problem continues to grow."

For Hochbaum, the beauty of algorithms

has always been in their utility in solving practical problems. Years ago, when she was working on her master's degree in mathematics at Hebrew University in Jerusalem, her professor handed her a challenge, one which begged for an algorithmic solution. The owner of a local shoe factory was losing one of his most experienced pattern cutters, a worker who was so good, he left no more than five percent of his leather as waste. Others left as much as 20 percent of wasted leather on the floor — waste the company could not afford.

The company wanted to know how to translate the retiring worker's skill into a prescription for efficient leather-cutting. Hochbaum worked on this problem for years without finding a solution. Like the traveling salesman dilemma, it was found to be intractable. Optimization problems such as these are called NP-hard, shorthand for nondeterministic polynomial problems. These are problems where no efficient algorithm exists, or is likely to exist, as a solution.

But years later, while tackling robotics motion problems, Hochbaum arrived at an approach that would have solved the shoe company's quandary. Her approach to solving NP-hard problems is to devise an algorithm for the problem based on an established limit of acceptable error. These "approximation" algorithms — the topic of Hochbaum's recently published book — work very quickly, and deliver a "good" solution. If speed is not the highest priority, another kind of algorithm that produces a "better" solution might be sufficient, though not as fast.

In approximation algorithms, the key is the limit of error. "For the robot motion problem, and the shoe problem, we can offer a trade-off. Once you tell me what error you're willing to live with, I'll give you the algorithm that will guarantee you this margin of error and no more," says Hochbaum.

For example, she could construct an approximation algorithm for the Israeli shoe factory that would provide the same limit of only five percent waste in pattern-cutting, but the time spent waiting for the algorithm to provide the solution would be much longer than if you could afford ten percent waste.

Several years ago, Hochbaum discovered that new ideas for solving problems sometimes come from surprising places and have unexpected applications. A Denver-based copper and gold mining company needed help with a variety of problems. Like other mining companies, this one was using software based on methods developed in the 1960s that helped plan and schedule where to dig, how to manage waste, and how to evaluate the efficacy of profit versus time and materials invested.

"The algorithm they were using was rather clever," says Hochbaum. "It worked, but it worked very slowly. I was sure I could find a faster solution."

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For Dorit Hochbaum, the beauty of algorithms lies in their utility for solving practical problems.

Hochbaum turned to the well-established tools of operations research and computer science, algorithms that had proven their mettle in the area of data flow in networks, and found an efficient technique that would work for the mining application.

But she also found, to her surprise, that the old algorithm used by the mining company turned out to have special usefulness in calculating network flow. The old algorithm even has application in the areas of transportation and sports.

"Our goal is to solve the practical problem, then extract from our solution the more general application," says Hochbaum. Sometimes the answer to a specific problem provides clues to unraveling much more fundamental challenges.

The newest offshoot of Hochbaum's research is an on-line library of optimization algorithms, presented in a user-friendly format on the World Wide Web, and developed with fellow faculty members Ilan Adler and Kenneth Goldberg. Users can embark on an open-pit gold mining expedition along a two-dimensional cross-section of earth, determining where to dig and how much time to spend looking for the buried gold, or they can track their favorite baseball team's standings in the pennant races [see story on facing page].

Hochbaum knows that visitors to the Web site will most likely come there first to play. But she hopes that a few will get curious about the technical underpinnings, and might even collaborate on future additions to the site. Those who stand to benefit from more collaboration include researchers across campus, as well as researchers in industry.

"I hope RIOT is just a small nucleus of what's to come," Hochbaum says. "I'd like industrial researchers and lay people to get an idea of how useful science can be in everyday life." F

BY NANCY BRONSTEIN

Hochbaum develops algorithms to solve a wide array of problems – from electronic circuit testing to logging management.