Physicist Leads Theory Group at Microsoft Research

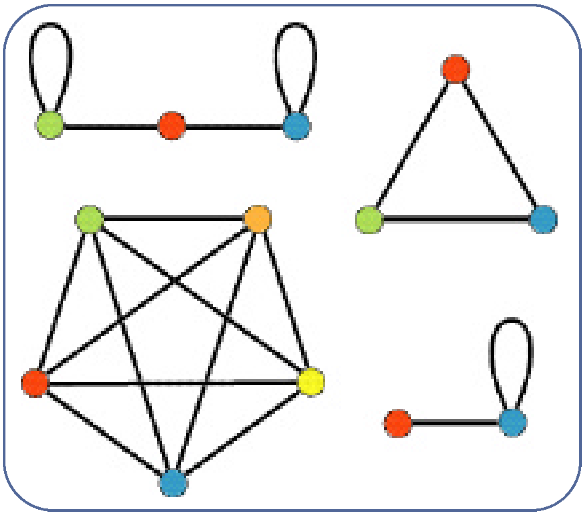
PROFILE

by Jennifer Ouellette

Grappling with the elusive solutions to today's increasingly complicated problems in computer science is an average day at work for Jennifer Tour Chayes, co-manager of the theory group at Microsoft Research, the software giant's research arm. Chayes is recognized as a world expert on phase-transition theory, particularly on the probabilistic and stochastic geometric approach to statistical physics. Since joining Microsoft Research four years ago from academia, she has applied her math and physics expertise to address problems in theoretical computer science, networking, and information technology, all with the aim of keeping Microsoft on the cutting edge of its field (www.research.microsoft.com).

Jennifer Chayes fosters collaborations to solve intractable problems

Chayes admits to some initial trepidation at switching from faculty to industry, particularly after attending her first Microsoft scientific seminars, which she compares to going back to the beginning of graduate school. "Everything sounded like Greek to me, and people were throwing around acronyms left and right," she says. Chayes had to struggle to make sense of the jargon and determine where her math and physics training could have a positive impact on the company's research activities. "It has been tiring, in the same way that being a grad student can be tiring, but it's also very exhilarating," she says. "It is discovery, and making useful connections between different fields is very exciting."



Marek Biskup

Figure 1. Constraint graphs help in studying the ratio between constraints and resources at which an intractable problem undergoes a phase transition between solvable and unsolvable.

Her interest in science and math began at age 5, when she spent time at a neighbor's house where a family of mathematicians frequently worked on problems together. Initially, she says, she began asking for her own math problems to gain the adults' attention, and problem-solving became an abiding passion as she moved on to more advanced endeavors. And her father, a pharmacist, would bring chemicals home and perform "experiments" for Chayes and her brothers, which kindled a corresponding interest in scientific experimentation. The experiments also paid off for her brother, James Tour, now a professor of chemistry, mechanical engineering, materials science, and computer science at Rice University.

Nevertheless, her career goal when she entered Wesleyan University (Middletown, CT) was to become a physician. "I thought I needed a 'real' career. Eventually, I realized that being a scientist was a real career," she says. Dreading her premed physics class, she scheduled it over a summer, found she truly enjoyed it, and gradually began taking more physics courses. Chayes earned bachelor's degrees in physics and biology and graduated first in her class. Nor did her passion for problem-solving end there. She continued with graduate studies at Princeton University, earning her Ph.D. in mathematical physics in 1983, and then embarked on a traditional career path in academia with postdoctoral appointments at Harvard and Cornell universities.

Impressed by their collaborative thesis on statistical physics, Arthur Jaffe, Chayes' postdoctoral advisor at Harvard, invited her and her first husband, Lincoln Chayes, to join his research group in Cambridge. Jaffe particularly noted Jennifer Chayes' persistence in following up on her work. "That's very important in a scientific career," he says. "You have to have good ideas, but you also have to pursue them, live through disappointment, and learn from your mistakes; and Jennifer is very good at doing that."

In 1987, Chayes joined the faculty of the University of California, Los Angeles (UCLA), with full tenure, where she remained for 10 years and garnered many teaching awards. "I really loved teaching," she says. "My students were a captive audience." Nor did she limit herself to discussing only details of a specific course with her students, offering career advice and insights into how science could benefit their lives.

A decade later, Chayes and her second husband, Christian Borgs, were hired to develop a new theory group for Microsoft Research, which conducts basic and applied research in computer science and software engineering (Figure 4). The goal of Microsoft Research is to

develop new technologies that simplify and improve the user's experience with personal computers, reduce the cost of writing and maintaining software, and facilitate the creation of new types of software.

To help accomplish this objective, the theory group explores the theoretical underpinnings of fundamental problems in computer science, using techniques from statistical physics and discrete mathematics. It brings together mathematicians, physicists, and theoretical computer scientists to work on problems at the interface of the three fields. The insights gained from the group's work may someday yield good sources of codes for cryptographic applications and new methods to solve problems such as scheduling and network routing.

"The work that Jennifer and the theory group is doing is a great example of Microsoft's investment in the future of technology," says Rick Rashid, senior vice president of Microsoft Research. Team members have published some of the industry's key papers, "regularly consult on product development, and have made contributions to Windows and Office products, among others."

Chief among the theory group's long-term goals—and the focus of much of Chayes' own research—is gaining an understanding of so-called intractable problems, known to physicists and mathematicians as nondeterministic polynomial hard problems or NP hard problems. Chayes is currently working on a subcategory of these, known as constraint-satisfaction problems, which she describes as systems consisting of constraints and resources. The ratio between the two can be used to determine whether or not a problem has a solution.

"In a very simplistic sense, if you have more constraints than resources, your problem is unsolvable, whereas if you have more resources than constraints, your problem is going to be solvable," she says (Figure 1). "But what is really interesting is that as you vary this parameter in a very large system, it seems to undergo a phase transition. We are hoping that by using some of the techniques and

Figure 2. Jennifer Chayes takes a break outside the Microsoft Research buildings in Redmond, Washington, seeking inspiration from a sculpture by Ulrich Pakker called Nebula Torcida.

Figure 3. Lunch mates in the Microsoft Research cafeteria include (left to right) Alexei Kitaev (visiting researcher from the Landau Institute in Moscow), Christian Borgs, Jacob Lurie (intern graduate student from the University of California, Berkeley), and Van Vu (postdoctoral researcher and assistant professor at the University of California, San Diego).

perspectives of physics, we can discover much more about these systems than if we just tried to solve the problems."

In the real world, this translates into such mundane applications as scheduling and network-routing problems, image processing, and simulating many physical systems. For example, an airline's computer system must be programmed to schedule flights that are full, but not overbooked, for optimal financial success. "It's almost like a kind of self-organized criticality," says Chayes. "The financial constraints push you to the phase transition of that problem."

Another major area is developing the cryptography of tomorrow. As online shopping becomes increasingly common, there is a corresponding need for better security to keep ahead of the learning curve of computer hackers. Unlike other applications, the goal of cryptography is to generate hard, unsolvable problems, such as picking numbers that are difficult to factor, so the encryption cannot be broken.

"A step in that direction is to understand where the hard problems are concentrated, and our analysis seems to indicate that they are concentrated at the phase transition," says Chayes. Once identified, the challenge then becomes finding an algorithmic means of using such problems to encrypt credit cards, for example.

In addition to the work on the application of phase-transition theory to complex problems in cryptography, the theory group is exploring novel approaches to combinatorics and graph theory, algorithmic theory, theoretical computer science, and alternative models of computation. The last is obviously of critical interest to Microsoft, whose success is directly tied to revolutionary advances in the computer industry. Much of the current activity in the theory group centers on quantum computation and quantum information theory. The group is also examining whether alternative computing methods could lead to qualitative increases in speed comparable to quantum computation, or whether, says Chayes, "there exists some sort of 'no-go' theorem that inherently limits the speed of certain classes of alternative models of computation."

Another of her interests is the so-called Potts model in physics, essentially a model of a magnet with at least three different states. She is applying this model to image processing, replacing the three or more discrete states with three or more colors of pixels (Figure 5).

A link to the past

Chayes' varied interdisciplinary background has proven to be an asset in her new position. "It has given me a very broad perspective and allowed me to identify analogies and apply paradigms from one field to another," she says. This is particularly true of her physics background. Chayes likens the current complexity of problems in computer science—routing huge amounts of information over ever-increasing networks, sophisticated cryptography, and image processing—with physics in the 1970s. "Physicists realized that we could never solve these problems exactly, but then Kenneth Wilson, Michael Fisher, Leo Kadonoff, and Benjamin Widom, among others, developed this wonderful way of looking at systems with second-order phase transitions."

In fact, it was Chayes' physics research on phase-transition theory that first piqued Microsoft's interest in her, according to Nathan Myhrvold, the company's former chief technology officer, who attended graduate school with her. Microsoft Research was Myhrvold's brainchild, and when he began looking for someone to build a world-class theory group, he quickly settled on Chayes.

"She was working in areas of mathematics and mathematical physics that I thought would have enormous potential impact on computer science," he says. "She also has a great combination of energy, enthusiasm, professional contacts, and a style of getting people involved with one another—all qualities I thought were vital to building the group."

Although she currently holds an affiliate professorship in physics and mathematics at the University of Washington, Chayes' teaching these days is geared more toward the interns and postdocs who come through Microsoft's theory group from all over the world. "It's a very friendly, cohesive, interactive group," she says. "We eat lunch together every day" (Figure 3). That collegial cohesiveness is a key difference she has found between working in academia and an industrial setting, along with the necessity of collaboration.

Fortunately, collaboration comes naturally to Chayes,

Figure 4. Husband Christian Borgs, senior researcher and co-manager of the theory group, joins Chayes at the white board.

who used the approach throughout her academic career, dating back to her collaborative thesis, which caused some consternation at Princeton. “Collaboration is considered to be a minus in academia, but it’s a huge asset in industry,” she says. “I love collaborating with people and have essentially nothing on my CV that’s singly authored.” And despite warnings from her advisors, she had no problem getting full tenure at UCLA.

Her commitment to collegial interaction and collaborative research extends to her choice of technical staff members. “We don’t hire people, even if they are absolutely brilliant, if we think they are going to sit in their office and solve problems on their own,” she says. “I am not against that, but let them do it in a university setting.”

Myhrvold agrees. “The skills for doing great research don’t always overlap with those for managing a group and motivating a team,” he says. “At Microsoft, it makes sense to have a collaborative team of researchers working on highly theoretical areas, but also able to collaborate with other researchers elsewhere in the company as we try to apply those theoretical ideas.”

The choice of personnel is especially important because the theory group has only eight permanent staff members. The rest of the collaborative research takes place with the approximately 150 visitors, mostly from academia, who spend time with the group each year. On arrival at Microsoft, Chayes quickly saw that covering so much interdisciplinary ground—physics, math, theoretical computer science, engineering—would be impossible without constant input from visiting scientists. She has made interdisciplinary work with visiting scientists the cornerstone of her research strategy in the theory group.

A personal benefit of Chayes’ position is the opportunity to work closely with her husband and co-manager, Christian Borgs. For four years, theirs was a commuter marriage between Los Angeles and Germany, where he was a professor of physics at the University of Leipzig. The couple met in 1984 at a physics summer school in France, but love did not bloom until 1992. When the Microsoft offer appeared, the couple jumped at the opportunity. “We went from this incredibly long-distance commute to co-managing a group with offices right next door to each other,” says Chayes.

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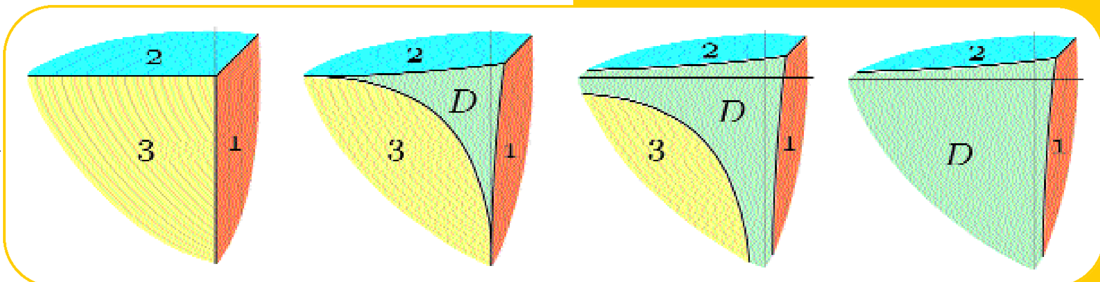

Figure 5. Line drawings depict phase diagrams of Potts model used to study image processing with three colors, where D is an area of disorder, or mixing.

On the Cutting Edge

Microsoft Research is dedicated to inventing or identifying the technologies that will shape computing 5 to 10 years into the future. Since its founding in 1991, the research facility has grown to include more than 600 people in areas that include speech-recognition technology, natural-language processing, data mining, three-dimensional graphics, programming tools, operating systems, networking, and user-interface research.

Ironically, Microsoft established its research arm when many U.S. companies were drastically reducing R&D, and the facility quickly earned recognition as a world-class corporate laboratory. “I feel very strongly that basic research is an important investment for a company to make,” says Nathan Myhrvold, who was responsible for founding Microsoft Research. “Although many other companies have stepped back from basic research, we have stepped forward, not just by building a research group, but by doing research that is quite theoretical.”

Microsoft finds useful applications from its basic research. According to Rick Rashid, senior vice president of research, the innovative work of its scientists is reflected in nearly every Microsoft product on the market. Microsoft Research has played an especially critical role in the Microsoft.NET initiative, a platform for the next-generation Internet in which constellations of computers, intelligent devices, and Web-based services will collaborate more closely than ever.

“Innovation is the lifeblood of technology,” says Rashid. “Microsoft continues to feel that investments in basic research and overall R&D are critical to its long-term success and meeting the needs of customers.”