



Bridging Mathematical Disciplines Helps IPAM Organizer Make Sense of Incomplete Data

With her focus on breaking down traditional disciplinary barriers, collaborating with researchers outside of her expertise and applying knowledge from one scientific arena to another, Maryam Fazel epitomizes many of the characteristics of IPAM. And so it's no surprise that in recent years, she has become an active participant and program organizer.

Fazel, an assistant professor of electrical engineering at the University of Washington, has been at the center of new developments at the intersection of optimization, data analysis and systems science. "These are three very different areas," she notes. "But all involve related mathematical problems, and it's typical that techniques from one area can also be used in another."

For the past several years, Fazel's main focus has been on the problem of estimating low-rank matrices amid incomplete or "noisy" information. A low-rank matrix is one in which the rows and columns of the matrix form a low dimensional space. For example, if a group of individuals rank their preferences

on a few items, the challenge becomes how to use that limited information to make inferences about unknown rankings.

"If we assume individuals tend to share certain tastes and preferences, then we can use the rank estimation to infer missing entries," Fazel explains. That ability to capture order and complexity from unknown or "noisy" information is of great interest in the "big data" era. "We have so much data, but also so much that is missing," Fazel says.

One of the most popular applications started in 2006 when the company Netflix launched a three-year competition for the best algorithm to improve its recommender system – extrapolating from customers' expressed preferences on movies to predict other movies they would like. Other applications include making predictions about people's political positions using data gathered for other purposes. The issue of estimating low-rank matrices is also of great interest in very different venues, including control engineering – for example, in the building of robots or aircraft.

Fazel's interest in this problem began a decade ago, when she was

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New Direction for Materials Science Research

effectively reducing the experimental time from hundreds of hours to 10 minutes. The finding led to an explosion in the brain-computer interface field, with applications that are both clinical and non-clinical. At the time Müller started, there were approximately a dozen research groups in the world; today, there are about 400.

In 2011, Müller was invited to bring his machine-learning perspective to CCS. Although his focus had been far afield from those of the other program participants, because Müller had been trained as a theoretical physicist their language didn't sound foreign. "After a couple of hours of listening to the talks, I realized I should know these topics," Müller says, laughing. "And I also realized that these were people I could help."

In informal conversations with colleagues at the IPAM program, Müller suggested an out-of-the-box strategy – using machine learning rather than the far more arduous density-functional theory to predict the outcome of a complex mathematical equation for assessing new molecules. The strategy proved viable, reducing the computing time for solving the difficult problem from roughly five hours to milliseconds, with the same accuracy.

That has led to what Müller calls "high dreams." He established several collaborations with other CCS attendees that are ongoing and have produced a number of papers – the first of which was submitted before CCS had even ended.

While the early work has focused on molecules, Müller and his collaborators hope to apply the new approach to materials science. Although far more challenging, it's a direction with substantial rewards. "If you want to know the properties of a superconductor or of some material that can serve as a solar cell or battery, that can take 3-4 months of computing time per material," Müller notes. "Imagine having the technology to go through millions of possible compound materials candidates to find the most promising ones for next-generation superconductors, which you would then analyze using the physics techniques. It's too early to say that we will be able to do this, but we have high hopes and so far we have not seen any limits to the potential for our methods."

Müller, who returned to IPAM at the beginning of 2013 as the main organizer of "Multimodal Neuroimaging" (delivering a public lecture entitled "Toward Brain Computer Interfacing") and will return for a visit during this fall's program "Materials for a Sustainable Energy Future," says the IPAM setting and format played a key role in sparking the new direction. "The great thing about IPAM is you have a lot of senior people who are away from their daily responsibilities and distractions," Müller says. "Everyone is in a different state of mind, has time to think, and is more open to new ideas. Added to that, you are spending long periods of time getting to know people in relaxed settings. That helps to develop a level of trust that you need when you are proposing a collaboration involving something radically different." ■

Missing Data

doing her Ph.D. research. “We had fewer tools and fewer motivating problems to work on back then, but it was still mathematically very interesting,” she says. Her group proposed algorithms to address the problem, but could not prove that they would always succeed. But over the next few years, a new area within the field of signal

processing gained momentum. Known as compressed sensing, it had a major impact on magnetic resonance imaging. In 2010, Fazel and her colleagues published a paper that was the first to make a connection between this compressed sensing approach to signal processing and low-rank matrix estimation. “Even though this was a completely different field, it turns out the mathematics is very similar,” she explains. The paper paved the way for a new research direction, both for Fazel’s group and for others, and set the stage for significant progress in the field of low-rank matrix estimation in the three years since.



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Fazel had attended IPAM workshops as a postdoctoral scholar, but her first significant involvement with IPAM was in the fall of 2010, when she was a core participant in IPAM’s long program “Modern Trends in Optimization and Its Application.” Coinciding with the publication of her group’s key paper, the three-month experience gave Fazel ample opportunity to interact with a wide variety of experts and continue drawing connections between the disparate research areas.

While at the 2010 IPAM program on optimization, Fazel met Lieven Vandenberghe, professor of electrical engineering and mathematics at UCLA and a member of the organizing committee. They identified two research areas, machine learning and system identification, that were tackling similar mathematical problems – both with the goal of constructing models from limited or noisy observations – but had little opportunity for interaction. After a subsequent discussion with IPAM director Russel Caflisch, Fazel and Vandenberghe organized a IPAM workshop held in January 2013, “Structure and Randomness in System Identification and Learning,” that brought the two research communities together.

“So often, you find people in different areas of engineering and the sciences who are working on the same foundational mathematical problems but using different terminology and techniques,” Fazel observes. “Making connections through shared mathematical problems and building bridges between these different scientific areas has been a theme in my own research, and it’s one of the great strengths of IPAM.” ■

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