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New mathematical frameworks reveal how stable thoughts emerge from chaotic brain activity

“The mind is what the brain does,” as the pioneering artificial intelligence researcher Marvin Minsky once said. So it’d be fantastic to understand at what level of anatomy, or complexity, the brain actually carries out its processing and computation.

This quandary is precisely what captivates Fatih Dinc, a postdoctoral scholar at UC Santa Barbara’s Kavli Institute for Theoretical Physics (KITP) and Geometric Intelligence Lab. His doctoral dissertation on this topic has earned Dinc the Richard C. DiPrima Prize from the Society for Industrial and Applied Mathematics (SIAM). The prize is awarded every two years, recognizing an early-career researcher in applied mathematics. Dinc was selected for his work developing a bridge between mathematics and neuroscience.

“Fatih is a deep thinker and his expertise vastly broadens the base of knowledge at KITP,” said Boris Shraiman, one of his postdoc advisors. “His work aims to shed light on the black box of AI, addressing the mystery behind present day machine learning, what makes it work and how similar, and how different, it is from the neural circuits of the brain. We’re proud to have him on our team.”

“Fatih is a visionary with a unique ability to bridge mathematical rigor with real-world applications,” added his co-advisor Nina Miolane, an assistant professor in the Department of Electrical and Computer Engineering. “Watching his research evolve from ambitious ideas into an internationally recognized, award-winning dissertation has been a privilege. The DiPrima Prize is a well-deserved recognition of his exceptional work.”

Making sense of bewildering complexity

The human brain may well be the most complex system we know of. The mind somehow emerges from the activity of around 85 billion neurons with some 100 trillion connections between them. “On a simpler level, imagine trying to understand a symphony by recording each musician individually,” Dinc said. “But in our case, the musicians keep switching seats and changing instruments from day to day. Also, you get to observe only 0.1% of the musicians at any given time. That's roughly the problem we face when studying the brain.”

Modern technology allows us to record the activity of millions of neurons simultaneously, and can track specific brain regions across many weeks. But individual neurons are unreliable narrators, Dinc explained: “A cell that responds vigorously to a stimulus on Monday might be unresponsive by Friday.”

However, the system clearly works. The brain reliably processes information and coordinates the functions of the body and mind. Dinc’s work is to reveal the brain's hidden language beneath the noise.

And he has a few goals. He wants to determine the fundamental unit of neural computation. If it’s not the individual neuron — which seems noisy and variable — then what is the right level of description? What’s more, he’s curious why behaviors remain stable even as the tuning properties of these individual neurons drift over time. Answering these questions requires figuring out how to make sense of data generated by a million neurons over several months.

An unexpected field of study

Dinc studied physics, and still considers himself a physicist. His integration into the field of neuroscience was quite accidental. In fact, he describes earning the Richard C. DiPrima Prize as “a bit surreal.”

Incoming doctoral students at Stanford, where Dinc earned his Ph.D., can enter a rotation that places them in a series of different labs on campus. Dinc decided to join Mark Schnitzer, a physicist studying the brain. “I quickly realized that the problems about the brain were mathematically rich and the data were extraordinary,” he said. “I never left.”

“To have work that grew out of that unlikely combination recognized by SIAM — a community I deeply respect for its rigor at the interface of applied mathematics and real-world problems — means a great deal to me.”

Identifying the motifs in the symphony

In his doctoral thesis, Dinc built algorithms that extract clean signals from terabytes of messy brain imaging data. He then developed the mathematical frameworks that explain how stable computation emerges from this apparent chaos.

The brain appears to encode information in relatively large, simple patterns embedded in a system that’s much more complex. “Think of it like this: Even though a symphony involves 80 musicians playing simultaneously, the emotional arc of the piece might be captured by just a handful of musical themes,” Dinc explained. “The brain is similar, thousands of neurons are active, but the meaningful computation might live in a 3- or 4-dimensional subspace.” Finding that subspace is the key challenge, because presumably it’s these larger patterns that account for the stability of the system.

Researchers around the world are already applying Dinc’s algorithms to process large-scale brain recordings. These tools enable the kind of data analysis that simply hadn’t been feasible in areas like pain, memory and motor control studies, among many others.

Meanwhile, his mathematical framework has direct implications for brain-machine interfaces. “If you want to decode intended movement or speech from neural activity, you need to know where in the high-dimensional neural space that stable information lives, and the framework provides exactly that,” Dinc said. More broadly,

understanding how the brain maintains memories and makes decisions informs how we might eventually treat disorders like Alzheimer's or Post Traumatic Stress Disorder, where those mechanisms break down.

Dinc believes his recognition reflects something important about how neuroscience is evolving. The most interesting problems seem to require the tools of applied mathematics, optimization and dynamical systems. “I hope the award draws more mathematically-minded people toward these questions,” he said. “The fact that I found my next home here at KITP means that this process has already started.”

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Artificial Intelligence

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