Physicists help to decode the brain

An increasing number of physicists are using their expertise to understand the human brain. Paula Gould spoke to several researchers who have made the move to neuroscience.

Doctors know that they can control epileptic seizures without having to perform surgery by placing the patient’s brain in an electric field. In doing so, they are exploiting the fact that an electric field can cause neurons to fire in synchrony. But they do not understand exactly how the process works. Eun-Hyong Park, a research associate at the Neural Engineering Center at Case Western Reserve University in the US, believes that is important to understand the way in which the neurons respond to the field. “This is an area where mathematicians and physicists can help,” she says. “You need to understand why these therapies work.”

Park is one of a growing number of researchers who have opted to apply their physics training to problems in neuroscience. Park initially completed a PhD and postdoctoral work in chaos theory and phase synchronization. She then moved to Case Western to apply the same theoretical tools to medical applications. “I wanted to expand my knowledge into a more applied field,” she says. “Synchronization prevails in nature in a lot of different areas.”

Dominique Durand, editor in chief of a new Journal of Neural Engineering published by the Institute of Physics, believes that the contribution of physical scientists and engineers is crucial to understanding the brain. “While neuroscientists and engineers from varied fields such as brain anatomy, neural development and electrophysiology have made great strides in the analysis of this complex organ, there remains a great deal yet to be uncovered,” he says. “The potential for applications and remedies deriving from scientific discoveries and breakthroughs is extremely high.”

Denis le Bihan, director of the Institute of Functional Neuroimaging, in Paris, agrees that physicists’ theories are critical to advancing treatment of neurological and psychiatric disorders. “Models and tools used today in high-energy physics could show how clusters of neurons work together,” he says. “In fact, the secrets of the brain could be in the hands of physicists.”

Le Bihan’s perspective on interdisciplinary collaboration is aided by his dual background in medicine and physics; he left college as a qualified medical doctor and with a PhD in physics. He has subsequently emerged as a world authority on magnetic resonance imaging (MRI), developing pioneering techniques to study acute brain diseases and connectivity disorders.

Le Bihan is currently overseeing plans for a new neuroimaging centre within the research campus of the French atomic energy commission (CEA) on the outskirts of Paris. The NeuroSpin complex will house four ultrahigh-field MRI units suitable for human and animal studies. The state-of-the-art scanners will offer sufficient spatial resolution to visualize neurons and neuronal connections directly. Scanner access will be split between full-time staff members and researchers from other institutions who have bought time slots, a concept more familiar to physicists than biological neuroscientists. “I do not say that NeuroSpin is exactly like CERN, but it provides a good working model for sharing large, expensive equipment,” says le Bihan.

Learning from biology

Physicists have much to learn from their colleagues in biological neuroscience too. “In physics you always try to use a simple model to explain experimental results, but neuroscientists always try to simulate everything in detail. They want a real model, not a simple model,” says Jianwei Shuai, a neurologist at the University of California, Irvine, who originally did a PhD in theoretical physics. He now uses tools from nonlinear dynamics to model the way cells communicate via calcium signalling. A lone theorist in a laboratory of experimentalists, Shuai now regards himself as both a physicist and neuroscientist. Yet it took a good three years to complete the philosophical transition, he says.

Zhaoping Li, reader in psychology and honorary reader in physics at University College London, is equally adamant that physicists should adopt an alternative mindset when moving into neuroscience. When interviewing prospective postdoctoral students, she quizzes them if they expect to be asking original questions about neurological systems themselves. “This is not a field where other people ask the questions and you just solve them. You need to ask the questions yourself. Open your mind to be more ambitious,” she says.

But this more creative approach can be quite daunting at first, says John Hertz, professor of biophysics at the Nordic Institute of Theoretical Physics in Copenhagen. Hertz trained in statistical physics and condensed-matter physics before becoming interested in disordered systems and eventually biological information processing. He worked first on spin glasses, systems with a highly irregular magnetic configuration. Spotting an analogy with neural circuitry, he then started to apply his ideas on magnetic systems to model memory. “Initially I really felt I was too ignorant about real neuroscience to dare say much about it. But gradually I got more confident,” he says.

Opening doors and minds

Experimentalists are also benefiting from closer collaboration with their theoretical colleagues, and recognizing the importance of theory within their discipline. “In the old days, experimental neurobiologists never read any theoretical papers. Everybody assumed they could do their own theory. But now people are realizing that a little higher level of mathematical abstraction helps,” he says. “When I go to neuroscience meetings, most people do not think of me as a physicist, they think of me as a computational neuroscientist.”

The route from physics to neuroscience is now easier, thanks to the advent of dedicated postgraduate programmes that help theorists catch up with biological knowledge, Hertz says. Many recent recruits to the field have been attracted by the novelty of neuroscience, he says. “Everybody is interested in how our brain works. Physicists are discovering that now you can study it in a useful way.”

Li urges physicists to take advantage of today’s welcoming climate in neuroscience, having battled for acceptance herself. “There is a growing community of people like myself, but, of course, I would like to see more,” she says. “We are the generation that has to make a difference. We have to make some kind of a breakthrough to demonstrate that theoretical neuroscience is having an impact and attracting new students, and become an established discipline rather than bordering on the boundaries of other departments.”