

The Brain. Pure and Simple. How Physicists Model the Mind

by Brian Blais

While walking on the 7th floor of Barus and Holley building, the home of the physics and engineering departments, one might be struck by what appears to be an out of place room labeled *Neural Science*. This is the laboratory of Dr. Leon Cooper, Nobel laureate and Professor of Physics, where several physics graduate students, including myself, and an assortment of postdocs, undergrads, and visiting scholars work to unravel some of the mysteries surrounding how the brain functions. Why is it that physicists would choose to study the brain, a topic which one usually associates with biology? Why choose this rather than pursue more traditional lines of research? Do physicists have something to offer to the field which others have lacked? These questions force us to look closely at the process of science, and how physicists like to look at the world.

One answer to the question is that it is currently becoming more fashionable for physicists to study neural science. This is in part a trend much like the trends in clothing, and in part because there is currently enough technique and technology for strides to be made in the field. But can such research be considered *physics*? The traditional physics curriculum does not encompass the topic of the brain, so the quick answer would be no, it certainly is not physics. Somehow that is an unsatisfying answer to me, for topic of research, alone, does not make the difference between physics and biology. Rather the distinction lies in the unique perspective that biologists and physicists take on a topic due to the differences in their training.

Their separate perspectives can best be seen through the differing goals of each type of scientist. Theoretical physicists theorize, obviously, but more specifically their theories simplify, as Einstein noted when he said that “theories should be as simple as possible, but no simpler”. This succinct description of the goal of the theoretical physicist also marks the biggest difference between training in biology and physics. Biologists are trained in the importance of particulars, whereas physicists are trained to ignore the particulars in order to identify the qualitative features of the problem.

An example of this can be seen in the superconductivity research of Dr. Cooper, for which he received the Nobel Prize. At the time, he was working to understand the reason why a simple material, like Niobium, would behave as a normal metal at one temperature and then become a superconductor at a lower temperature where it suddenly has no resistance to electrical current and repels magnetic fields, both qualities quite different than normal. Understanding all of the properties of a solid, with its large number of atoms and interactions between them, would be an impossible task: the details would be overwhelming. Dr. Cooper summarizes his approach, saying “there is an important *qualitative* difference between the superconducting state and the normal state. What are the *minimum* assumptions that can achieve this qualitative difference?”

When modeling the brain, physicists use the same approach. Models are propose which address the *qualitative* properties first, and only refined later when those properties are satisfactorily handled. For example, we can start by looking at the smallest independent parts of the brain, the neurons. Each of these incredibly complex cells contains a myriad of ion channels,

receptors, and neurotransmitters all working together, each cell adding one piece to the process we call thinking. As in the case with the superconductor, we choose to ignore most of the details and model neurons as simple circuit elements, with inputs and outputs, and some very rudimentary processing inside. In the standard physics fashion, this ignores many details of the way the neuron functions but it captures some of the qualitative features. We can then look at some of the basic properties of the neuron, such as learning and memory storage, and try to figure out what minimum assumptions we require in our model to reflect these properties. We can then use these simple model neurons to form a network, and try to understand how such things as cognition can arise out of the interaction of many simple units. Again the minimum assumption rule is used, so that we don't drown in the details.

The model must always refer back to experiment in order to know which properties are the ones found in nature. All of this, of course, requires a close interaction between theorists and experimentalists, a crucial element to the proper working of scientific inquiry. According to Professor Cooper, "the job of the experimentalist is to tell us what is out there in the world, in contrast both to what is *not* out there in the world and what we would *like* to be out there. Theorists who are not in contact with this are spinning their wheels, because imagination and the world need not agree." Without the experimentalists, the theorists would be working in a closet, and without the theorists the experimentalists may not know which tests are the most critical to perform in order to advance our understanding of the system.

There is more of a difference between physicists and biologists studying the brain than merely the simplicity of the theories. Though the brain is a biological system, the problem is not a purely biological one. The brain performs some very sophisticated information processing. Biologists are not traditionally trained to handle such problems, whereas physicists are. There are many classic problems in physics where a system, made up of many simple units interacting with themselves and the environment, yields qualitatively different behavior than the individual units themselves. The physicist looks for the parallels between these classic problems and the problem of the brain, and thus looks at the entire topic differently.

Professor Cooper notes, however, that there is a problem with physicists studying biology. Often "they don't take the biology seriously. They expect that they can write down a couple of equations and be done with it." This is a result of the physicist presuming that the problem is inherently simple like many of the systems the physicist is accustomed to. This presumption often helps to avoid unnecessary complexity, but it also ignore some of the *necessary complexity*. These differences between standard biologists and standard physicists, or theorists, is not quite as striking now as it was in the past because more and more people are trained in both biology and physics. As is the case when any field grows, the next generation of scientists is better able to handle the problems which the previous generation found difficult. Then perhaps the line between physicists and biologists will become hazy or disappear altogether, reaping the benefits of both approaches and allowing the scientist of the future to gain a full understanding of this amazing biological organ, the brain.

For the physicist, the brain is a large system of interacting elements perhaps like the atoms in a solid or the stars in a galaxy. Though we are far from understanding even the most basic functions of the brain, the future holds great potential. We look out into the universe in the same way as we look into our own minds, searching for some understanding.