Neuro-turbulence

The erratic, disordered dynamics exhibited by fully turbulent fluid motion is amongst the most complex and challenging phenomena in nature. Turbulence dictates dissipation, drag and mixing rates in areas as diverse as astrophysics, engineering and biology. It plays a vital role for the earth's climate as well as for nutrient transport in the oceans. Recently it has been shown that there is a deep connection between the onset of turbulence and the dynamics of action potentials in a nerve axons. These insights have are providing remarkable clarification and simplification of our understanding of the onset of turbulence.

The development of simple models for the transition to turbulence has opened new areas of study and there are currently many high-value questions that can be addressed with simulations of model equations. This mini-project would involve simulating model equations to addresses one or two key issues with potentially immediate impact:

1. There is strong evidence that the onset of turbulence in pipe flow is a directed percolation (DP) transition. However, the critical exponents are currently inaccessible to experiments. It is therefore quite important that the critical exponents for the model equations be fully determined numerically and compared with expected values for DP in $1 + 1$ dimension.
2. Because turbulent patches in pipe flow behave remarkably like action potentials in neurons, there is a host of important questions to address. In particular, one would like to understand in detail the speeds of turbulent patches.

The model equations are similar to the FitzHugh-Nagumo equations for action potentials in nerve cells but with the necessary additional advective terms found in fluid flow. The equations are

$$\frac{\partial q}{\partial t} + (u - \zeta)\frac{\partial q}{\partial x} = f(q,u) + D\frac{\partial^2 q}{\partial x^2}, \quad \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} = \epsilon g(q,u)$$

where q represents a turbulent field and u the mean flow. D, ζ, and ϵ are constants, and f and g and nonlinear functions. A C code that simulates the equations already exists, although it would need modification for the purposed of the project.

This research project involves active collaborations with experimental and computational groups in Paris, Germany, and Austria. We have recent high-impact publications and are currently working on others. The expectation is that there are several important results yet to come. While a 12 week mini-project is probably not sufficient to obtain publishable results, the goal would be to work towards something publishable. There are many long term projects underway involving both fundamental statistical physics and applied aspects such as control. For long term work, this project would involve some combination of simulations of model equation, theoretical analysis of model equation, simulations of the full Navier-Stokes equations for fluid flow, and/or processing of experimental and numerical data.

For further information, see Dwight Barkley's web page.