The Abdus Salam
International Centre for Theoretical Physics

Minischool and Workshop on Mulitple Time Scale in the Dynamics of the Nervous System
16 to 29 June 2008, ICTP, Trieste, Italy

` Fast and slow dynamics in neural networks with small-world connectivity'

Sara A. Solla
Physiology, Dept. of Physics & Astronomy, Northwestern University, Chicago, USA

ABSTRACT:

An understanding of emergent dynamics on complex networks requires investigating the interplay between the intrinsic dynamics of the node elements and the connectivity of the network in which they are embedded. In order to address some of these questions in a specific scenario of relevance to the dynamical states of neural ensembles, we have studied the collective behavior of excitable model neurons in a network with small-world topology. The small-world network has local lattice order, but includes a number of randomly placed connections that may provide connectivity shortcuts. This topology bears a schematic resemblance to the connectivity of the cerebral cortex, in which neurons are most strongly coupled to nearby cells within fifty to a hundred micrometers, but also make projections to cells millimeters away. We find that the dynamics of this small-world network of excitable neurons depend mostly on both the density of shortcuts and the delay associated with neuronal projections. In the regime of low shortcut density, the system exhibits persistent activity in the form of fast propagating waves, which annihilate upon collision and are spawned anew via the reinjection of activity through shortcut connections. As the density of shortcuts reaches a critical value, the system undergoes a transition to failure. The critical shortcut density results from matching the time associated with a recurrent path through the network to an intrinsic recovery time of the individual neurons. Furthermore, if the delay associated with neuronal interactions is sufficiently long, activity reemerges above the critical density of shortcuts. The activity in this slow regime exhibits long, chaotic transients composed of noisy, large-amplitude population bursts.

References:

1. Roxin A, Riecke H, Solla SA.
Self-sustained activity in a small-world network of excitable neurons.
Physical Review Letters 2004 May 11; 92:198101.

2. Netoff TI, Clewley R, Arno S, Keck T, White JA.
Epilepsy in small-world networks. Journal of Neuroscience 2004 Sep 15; 24(37):8075-83.

3. Dyhrfjeld-Johnsen J, Santhakumar V, Morgan R, Huerta R, Tsimring L, Soltesz I.
Topological determinants of epileptogenesis in large-scale structural and functional models of the dentate gyrus derived from experimental data. Journal of Neurophysiology 2007 Feb; 97(2):1566-87.

4. Riecke H, Roxin A, Madruga S, Solla SA.
Many attractors, long chaotic transients, and failure in small-world networks of excitable neurons.
Chaos 2007 June; 17:026110.

5. Feldt S, Osterhage H, Mormann F, Lehnertz K, Zochowski M.
Internetwork and intranetwork communications during busrting dynamics: Applications to seizure prediction.
Physical Review E 2007 August 20; 76:021920.