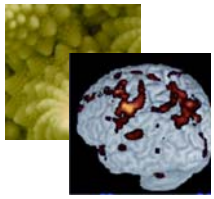
IFISC

BIOLOGICAL PHYSICS AND NONLINEAR PHENOMENA IN ECOLOGY AND PHYSIOLOGY

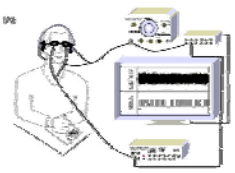


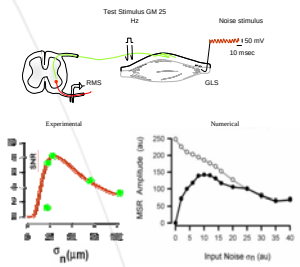
The general topic of this line is the study of some biological systems, mostly under the prism of modern Systems Biology, i.e. from the tenet that most observed behavior in living systems stems from complex, emergent interactions among its constituents. Present research topics include the dynamics of neuronal systems, with special emphasis in stochastic effects and synchronization properties, drug transport and absorption, population dynamics, phylogenetic networks and ecological structure and dynamics, including growth, aggregation processes and spatial effects, with special focus to clonal plants and savannahs. Methods of complex network analysis, stochastic simulations, and the theory of nonlinear dynamical systems are used thoroughly.

NEURONAL SYSTEMS

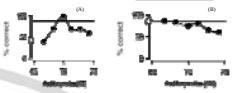
• *Stochastic effects: constructive role of noise in the nervous system*

In sensory systems, the presence of a particular nonzero level of noise may significantly enhance the ability of an individual to detect weak sensory stimuli through a phenomenon known as stochastic resonance.





Upper panel: scheme of the experiment. Bottom panel: SNR vs noise intensity. Experimental results (left) numerical results (right).Black line: subthreshold stimulus; grey line: suprathreshold stimulus.

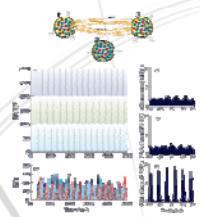


Psychophysical experiments: subthreshold (A) and suprthreshold (B) stimuli.

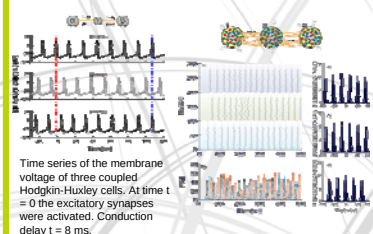
The ability of a subject to detect sub-threshold visual stimulus can be enhanced by a particular intermediate level of auditory noise. This effect is called cross-modal stochastic resonance.

• *Synchronization on neurons and neuron populations*

Zero time-lag synchronization among remote cortical areas have been observed despite the axonal conduction delays among such distant regions can amount to several tens of milliseconds. A simple network motif, containing a relay element between two neurons or neuron populations, reveals that, even in the presence of large axonal conduction delays, distant neuronal populations self-organize into lag-free oscillations.



Dynamics of two large-scale networks interacting through dynamical relaying. Panel a): raster plot of 300 neurons. Panel b): firing histogram of each subpopulation of 100 randomly selected neurons. Panel d), e) and f): averaged cross-correlogram between 1 & 2, 2 & 3 and 1 & 3, respectively.

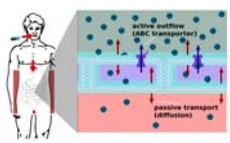


Time series of the membrane voltage of three coupled Hodgkin-Huxley cells. At time t = 0 the excitatory synapses were activated. Conduction delay t = 8 ms.

On the contrary two neuron populations directly connected synchronize at a time that corresponds to the time it takes the information to travel from one population to the other.

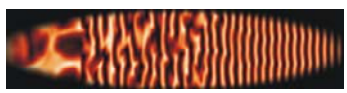
DRUG TRANSPORT AND ABSORPTION

Passive absorption in the small intestine is accompanied by active transporter proteins for many drug compounds. The same mechanism is responsible for cancer cell's drug resistance to a wide range of drugs. The transporter's activity depends non-linearly on the concentration.



PATTERN FORMATION IN EMBRYOGENESIS

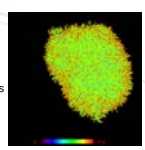
The creation of segments (i.e. the vertebrae) in vertebrates has been shown to be coordinated by a quite precise molecular clock, which is used by the embryo to measure distance. As a result time periodic information is converted into a space periodic pattern, namely a pattern of stripes. This is an example of how cells form tissues. Our theoretical description of the system is in terms of a drifting oscillatory medium in a finite domain, in which coherence in the transverse direction is achieved through cellular interactions. This description sheds also light on turbulent regimes, that are confronted with experiments carried out on zebra fish embryos.



ECOLOGICAL STRUCTURE AND DYNAMICS

• *Space colonization of clonal plants*

Rhizomatous plants are present in a broad range of ecosystems, both terrestrial and aquatic, that exhibit highly organized clonal growth progressing according to simple rules. Seagrasses like *Posidonia oceanica* or *Cymodocea nodosa*, as well as the harmful terrestrial invasive plant *Carpobrotus affine acinaciformis,* are typical examples found in the Mediterranean basin. The implementation of nonlinear growth models provides a capable tool to analyze the complex growth behavior observed among these species, determine the efficiency to spread their clones and design colonization strategies.

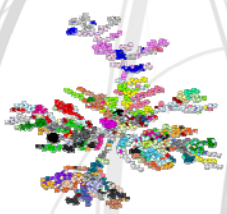


Model output: 6 years old patch of *Cymodocea nodosa* occupying a linear extension of 20 m.

• *Tree-tree competition and fire on savanna structure and dynamics*

The mechanisms regulating savanna tree populations are still not well understood. Recent empirical work suggests that both tree-tree competition and fire are key factors in savannas. We develop a stochastic cellular automaton to study the individual and combined effects of competition and fire on savannas. We find that while competition often strongly depresses tree density, fire generally has little impact, but can drive tree extinction in extreme scenarios. When combined, competition and fire interact nonlinearly, magnifying each others negative effects on tree density. This is a novel result that may help explain several observed phenomena in savannas. In particular, the characteristic regular tree spacing driven by competition maybe substituted by a spatial clustering.

ECOLOGICAL AND PHYLOGENETIC NETWORKS



The genetic relationships between taxa, populations, and individuals, are conveniently represented by trees and networks at different scales: on one extreme, the Tree of Life is a representation of the evolutionary relations of organism on Earth. On the other one, networks of genetic similarity can be constructed by linking relatives in a biological population. Network theory tools can be applied to them to extract relevant biological information. On the right: a rendering of the first branches of the Tree of Life, a population network of the marine plant Posidonia oceanica in the Mediterranean, used to infer gene flow, and a intrapopulation network of genetic similarity of ramets of this plant.

The figure on the left shows the minimum spanning tree (i.e. the one which minimizes genetic distances along their branches) containing all sampled ramets of Posidonia oceanica. Each node represents a shoot, with colors (or grey shades) indicating the sampling meadow, and each link has an associated distance.