Experimental realization and mean-field dynamics of a globally-coupled network of semiconductor lasers

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The dynamics of ensembles of coupled systems is a key question in many fields of research including laser dynamics, where there have been some implementation of mutual coupling configurations [1] [2], but also neurosciences, as in the case of epilepsy [3], and even social phenomena. Even though the ensembles may be large, in many cases the dynamics can be remarkably simplified analytically via a simpler mean field model that allows to reduce the dimensionality of such complex systems [4] [5] [6]. That said, experimental realizations of such large-ish networks are relatively scarce.

In this contribution we devise an optical experiment in which a large number of semiconductor lasers are coupled from a one-to-all to an all-to-all network configurations, each of them mimicking the dynamics of chaotically spiking neurons [7]. We obtain this global coupling thanks to an opto-electronic feedback loop, where the intensity of the light emitted by a subset of the population of lasers is re-injected into the laser control parameter after undergoing a nonlinear function and a high-pass frequency filter. We then measure experimentally the bifurcations undergone by the fully connected network for different coupling configurations. It has already been shown that with one single laser one can obtain a sequence of slow chaotic spiking as a result of the coexistence of three different characteristic time scales, which span about five orders of magnitude. Here we increase our population to about 500 semiconductor lasers, and we study the emergence of chaos and synchronization as a function of the distribution of the lasers that are selected for the feedback. In particular, as we increase the population size, we observe that the system converges toward a clear limit.

Using a model of the laser spiking network where the dynamics of each node is described in terms of (single-mode) semiconductor-laser rate equations and the coupling mechanism is provided by a common AC-coupled nonlinear feedback loop, we are able to reproduce the experimental results with numerical simulations. Furthermore, from an analytic study of the model, we derive a simplified mean field model which is able to greatly reduce the dimensionality of the system and to well replicate and explain the behaviour of the whole population.

Références

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