In de verdediging

| In defence

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Stochastic Resetting and Hierarchical Synchronization
Janusz Meylahn

In September 2019 Janusz Meylahn from Leiden University successfully defended his PhD thesis with the title *Stochastic Resetting and Hierarchical Synchronization*. Janusz carried out his research under the supervision of prof. dr. F. den Hollander and dr. D. Garlaschelli from Leiden University.

During his PhD Janusz worked on two independent research projects. The one project concerned rare event probabilities of certain observables of stochastic processes when the process is reset at a certain rate. In the second project he studied interacting oscillators and their ability to synchronize.

Stochastic resetting
The object of interest in this research project on stochastic resetting was a homogeneous continuous-time Markov process denoted by $\{X_t: t \in [0,\infty)\}$. This is a continuous-time process whose evolution can be predicted only by knowing solely its present state. Stochastic resetting modifies the process to a new process $\{X^r(t): t \in [0,\infty)\}$ that restarts from some point in the state space which is chosen from a probability distribution. The time between two consecutive resets is considered to follow an exponential distribution with rate $r > 0$. For this process with resetting Janusz studied rare event probabilities of certain observables. To be more precise, the observables he considered are integrals of functions of the process, which constitutes the entire trajectory relevant for these probabilities. This was in contrast to previous studies on the addition of reset (the restarting mechanism) that have focused on observables like the position, which is not dependent on the entire trajectory, but only on the part after the last reset. Janusz showed that the process with resetting and the process without resetting are related in two ways. The first is through a functional equation relating the Laplace transforms of the generating functions of the observables of the two processes. Such a functional equation naturally leads to the question whether the large deviation behavior of the process with resetting can be determined based on the behavior of the process without resetting. Janusz showed, for the case of Brownian motion, how the large deviation probabilities for the two processes relate to each other. In order to determine the large deviation behavior of the process with resetting it suffices to know the large deviation behavior of three quantities, those are:

(a) The process without resetting.
(b) The number of resets per unit of time.
(c) The duration of the reset periods.

Such stochastic processes with resetting arise in various settings, one example is the PageRank algorithm. In this algorithm a random walker moves on a graph representing the World Wide Web. An initial probability distribution is placed on the set of nodes and, as the walker makes its way through the graph, the distribution is updated. The walker restarts from a node drawn uniformly at random at a constant rate.

Synchronization in the two-community noisy Kuramoto model

The second project Janusz worked on concerned oscillators interacting with each other, the interaction is represented by a graph where the oscillators are placed on the nodes and an edge between two nodes indicates that the corresponding oscillators interact. The challenge is to understand the effect the underlying network structure has on their ability to synchronize. Synchronization is a phenomenon that has fascinated scientists since Christiaan Huygens observed "an odd kind of sympathy" between the pendulums of his clocks designed for time-keeping on ships in the seventeenth century. Examples of synchronization in nature are copious. To mention but a few, synchronization is often observed among populations of insects, for example crickets chirping and fireflies flashing. It also controls circadian rhythms, power-grids and the suprachiasmatic nucleus (the body-clock), which is a cluster of neurons in the brain of most mammals.

In order to understand the emergence of synchrony and its importance for the body-clock Janusz introduced the two-community noisy Kuramoto model as a model for the suprachiasmatic nucleus. The Kuramoto model was introduced by Yoshiki Kuramoto in 1975 to model the phenomenon of synchronization. In the two-community noisy Kuramoto model the oscillators are grouped in two communities, and the interaction between the two communities can either be positive or negative. The negative interaction between the communities enriches the model significantly. A heuristic argument led to the conjecture that the only steady states of the system occur when the phase difference between the average phases of communities is equal to 0 in the case the interaction is positive, and equal to π in the case the interaction is negative. The intuition for this conjecture is that the system will try to maximize the interaction strength between oscillators in order to achieve the highest synchronization in each community. And now the magic comes, the steady-state solutions can have three different tastes, unsynchronized, symmetrically synchronized and non-symmetrically synchronized. Unsynchronized solutions correspond to no synchronization while symmetrically synchronized solutions correspond to the case where the synchronization level is the same in both communities. Non-symmetrically solutions are solutions where the synchronization level is non-zero but not the same in both communities! Janusz managed to find numerically the bifurcation line at which the symmetric solutions split off from the symmetric solutions. But what does such a result actually reveal about the body-clock? In experiments it has been observed that some animals can transition to a state in which the suprachiasmatic nucleus is anti-aligned, which might be explained by this result.

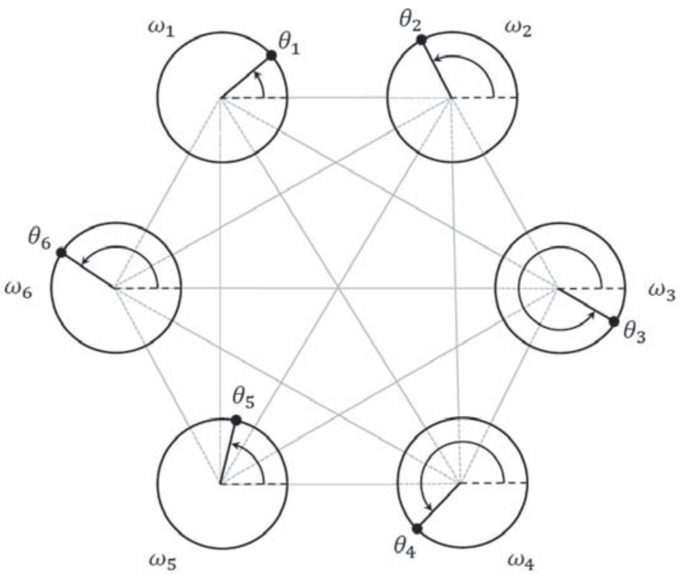

Figure 1 Six oscillators with natural frequencies ω_i and phases θ_i, $i = 1,\ldots,6$. All the oscillators interact with each other (mean-field interaction).

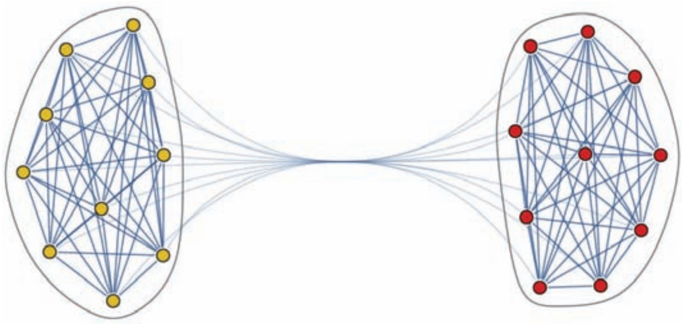

Figure 2 Schematic picture of the two-community network, with community 1 consisting of N yellow nodes and community 2 of N red nodes. The interaction between yellow nodes has strength K, between red nodes strength K and the interaction between the two communities has strength L.

The more personal aspect

Behind all dissertations there is always a person, with flesh and bones, who has endured the long path of a PhD trajectory and has produced the work at hand.

Janusz, alongside your research did you participate in other activities or events during your PhD?

"My research project was part of the NETWORKS program. Every year two training weeks were organized for all members of the program, these included mini-courses, lectures, research talks and open problem sessions. I thoroughly enjoyed the training weeks, which allowed me to learn a lot from a variety of disciplines, and to interact with many people.

Moreover, in 2017 I was allowed to go to the ICTS Large Deviation Theory Conference in Bangalore, India, together with my supervisor and some other PhD students. There I presented my research and got to interact with an international group of researchers."

What are the challenges and the things you like in your new position?

"Currently I am doing a postdoc at the University of Amsterdam on colluding pricing algorithms. It is a completely new field, which requires me to learn many new things. The most challenging difference from what I was doing before is that the oscillators I considered in my PhD where reacting to one another in a predefined way, while the competing algorithms can come up with a huge number of strategies in their interaction."