Title of thesis:

Stochastic computing using synthetic multicellular consortia.

Objective of thesis:

We will develop robust computing techniques based on synthetic biology and stochastic computing principles. Stochastic gates will be designed using Markovian probabilistic models and will be physically implemented as reversible recombinase modules in bacteria. The gates will be connected using cell-cell communication. We will work out the theoretical possibilities in terms of problem solving, such as constraint satisfaction problems. The theoretical predictions will be tested on the biological model.

Problem

Stochastic computing has appeared as an extension of computation by deterministic automata. The principle of stochastic computing is to solve problems by combining strings of random bits generated by noisy components [1-3]. Thus, stochastic computers are inaccurate, but the error is bounded and independent of the functioning conditions. As publicized in the one of the first papers on the subject by Brian Gaines [2], a stochastic computer ñis particularly fascinating because it uses what is normally regarded as a nuisance or waste product-random noise.òAlthough the speed limitation of digital computers was largely overcome and nowadays one has effective and rapid digital solutions for many problems, the stochastic computing still remains competitive for applications where errors need to be kept within bounds with economy of resources. Examples of recent applications are the low-density parity-check codes used for communication over noisy and error-prone channels [4]. Other applications to large scale optimization, machine learning and signal processing can be envisioned.

The advantage of stochastic computing is threefold: (i) it is robust, i.e. it provides solutions close to optimal in spite of random perturbations, (ii) it can solve hard problems by combining random search and parallelism, and (iii) it is evolvable, i.e. partial solutions can be improved by iteration.

Historically, this idea did not lead to new machines, but to new algorithms to solve computationally hard problems, such as particle swarm or ant colonies intelligence. Indeed, stochastic computing is highly relevant to the study of biological systems in which precise and robust behavior emerges as a collective behavior of noisy components. With the advent of synthetic biology it is now possible to engineer living cells implementing stochastic logical operations and communicate one to another in order to solve a problem. In this thesis we will combine mathematical and experimental approaches to study the capacity of networks of stochastic gates to solve combinatorial problems, such as constraint satisfaction. We will use mathematical models based on Markov processes to design several instances of stochastic computers which will then be experimentally implemented within a synthetic multicellular consortia of bacteria performing distributed computation using bio-molecular logic gates and engineered cell-cell communication systems.

Bibliography

[1] Armin Alaghi and John P Hayes. Survey of stochastic computing. *ACM Transactions on Embedded computing systems (TECS)*, 12(2s):92, 2013.

[2] Brian R Gaines. Stochastic computer thrives on noise. *Electronics*, 40(14):72ï 79, 1967.

[3] BR Gaines. Stochastic computing systems. In *Advances in information systems science*, pages 37ï 172. Springer, 1969.

[4] Peng Li and David J Lilja. Using stochastic computing to implement digital image processing algorithms. In *Computer Design (ICCD), 2011 IEEE 29th International Conference on*, pages 154ï 161. IEEE, 2011.