**Designing collective swarm intelligence through dynamical fluctuations: Making rare behaviour typical**

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A central aim of current robotics is to devise protocols for collective intelligence via the self-organisation of a swarm of robotic units to perform certain desired tasks in a robust and reliable manner [1]. Strategies to achieve this are often inspired from biology where examples abound of systems composed of many simple units which collectively self-aggregate into complex structures or self-organise to perform complex tasks [2]. The key design problem is to establish the interactions between the units that will give rise to the desired collective behaviour. In physical sciences this is known as the inverse problem, since in most physical systems interactions are a given, and exploration focuses on understanding the consequent outcomes.

The inverse problem is notoriously hard, but biology has found solutions. An illustrative example is that of protein folding [3]. In proteins the interactions are determined by its amino-acid sequence. The space of possible sequences is enormous, but only a small fraction of sequences provide interactions that allow proteins to self-assemble reliably to its functional native structures. Through the very slow process of evolutionary dynamics, nature has explored the vast and complex landscape of possible sequences, eventually converging on optimal sequences that allow proteins to fulfil their biological function. In artificial systems, however, the very long evolutionary times of biology are not possible. Strategies need to be devised to accelerate the optimisation process of finding the correct interactions between agents in a swarm. While in certain situations this can be done by inspection the likely outcome is a set of very specific interactions that may lack versatility or robustness under perturbations in the swarm's environment. A general and flexible approach is therefore highly desirable.

We propose to devise a general approach to the problem of design of interactions in a robotic swarm based on exploiting rare dynamical fluctuations through methods borrowed from the mathematics of Large Deviations [4]. Imagine a swarm subject to environmental noise and perturbations where the interactions between agents have not been optimised. Typical behaviour in such a system will be very far from that which is desired, measured for example through some figure of merit that quantifies the difference in the behaviour of the swarm with respect to the target task over a period of time. Occasionally however, due to the presence of noise, there will be rare trajectories of the swarm that are very far from the typical and closer to the desired outcome. While this will occur by chance, it is known from the theory or Large Deviations that the statistics of these rare fluctuations contain information about the interactions the swarm should have had to perform the task reliably. This is the key to the dynamical design procedure: by careful analysis of dynamical fluctuations, the interactions between the agents in the swarm can be progressively tuned, through feedback and control, towards those that will allow it to perform the target task reliably. This is a procedure to convert rare behaviour into typical behaviour.

This approach is already applied with success in physical and material sciences, for example to achieve complex non equilibrium states of matter such as glass [5]. There is no reason in principle why these novel ideas cannot be applied to robotic systems, offering the great advantage of automatisation of the design process for the interactions in a swarm in a robust and general way. The aim of our project is to provide proof of principle of this approach and methodology, first *in silico*, and then in the lab, by considering in the first instance swarms composed of a small number of robotic units performing simple tasks. This proof of principle will then allow us to scale up the approach towards larger swarms performing tasks of increasing complexity.

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