Swarm Robotics : Distributed Online Learning in the realm of Active Matter

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DESCRIPTION
Swarm robotics designates large groups of robots with limited communication and capability, that coordinates on a local basis to achieve tasks that can be evaluated on a larger scale. Typical examples are: collective construction (Werfel et al. 2014), self-assembly into specific patterns (Rubenstein et al., 2014; Slavkov et al., 2018), collective transport and exploration (Bayindir, Sahin, 2007, Li et al., 2019).

The complex collective dynamics between individuals and the unpredictable nature of real-world environments make it very difficult to hand-code or optimize swarm behaviors prior to deployment. This is particularly true when a dense swarm of robots is considered, which is often the case with large low-cost robots for object transportation and coordinated swarming (ie. moving while staying close to one another). In that case, the multiple physical interactions between robots can be very difficult to model, and the classic approach in swarm robotics is to avoid these as much as possible.

However, physical interactions between self-propelled particles is well studied in physics of active matter, and can actually lead to very interesting collective behaviors even without any computation capabilities. Self-propelling vehicles without any onboard CPU, such as small millimeter-scaled grains, have been shown to display aggregation, dispersion and swarming in a coordinated fashion (to name a few examples) solely due to collisions and physical characteristics (e.g. shape or kind of friction on the ground).

The goal of this thesis is to investigate how distributed online learning process mimicking social learning (Bredeche, 2018), can be used to discover and exploit primitives available at the physical level. It will take place in the more general context of an ANR project, the goal of which is to propose a interdisciplinary viewpoint of swarm robotics, in order to leverage what can be freely provided by physics, when designing computational decision making algorithm.

In swarm robotics each robot exchanges its control parameters, which quality is assessed by an onboard objective function, and the objective is to display microscopic behaviour that combined together give rise to a desired macroscopic organisation. The learning abilities of the swarm of robots is related to the dynamics of their internal parameters in an unknown and complex energy landscape.

From the point of view of physics, a swarm of robots can be seen as a fluid, composed of self-propelling units, a so-called “active liquid”, in which the individual units carry a discrete set of interacting policy’s parameters.

On one hand, the physics of simple active liquid has recently converged towards a good level of theoretical understanding. This includes the description of two dynamical phase transitions, which are specific to active matter, namely the transition to collective motion and the motility induced phase separation. From the point of view of swarm robotics, the existence of these spontaneously forming phases, that of collectively moving units, or that of spontaneous clustering, indicate that a number of primitive, yet collective, tasks can be achieved without requesting for the logical or computational abilities of the robots.
On the other hand the dynamics of the interacting policy parameter in a complex energy landscape is typical of the physics of disordered magnetic systems, for which important conceptual progress have also been achieved.

We propose to investigate numerically a model of behaviour learning, distributed on a set of mobile agents, as one would do for an active liquid of particles carrying internal degrees of freedom, which couple dynamically to the motion of the particles (Tarzia, 2020). We will investigate the interplay between the learning process, which evolves the dynamical rules of the agents, and the underlying physical primitives, which condition the large scale phases available to the swarm. The expected outcome is both a practical learning algorithm for dense swarm robotics, and theoretical results about the dynamics of collective learning in a physical setup.

**The originality of this thesis**, is to consider the online distributed learning as part of a more general dynamical process, including both the learning dynamics and the physics of the robots as an active liquid.

This interdisciplinary Ph.D. thesis will be advised by Nicolas Bredeche, a computer scientist specialised in swarm robotics and evolutionary robotics, together with Marco Tarzia, an expert in the fields of liquid state theory and disordered systems, and Olivier Dauchot, an expert in active matter.

**ADMINISTRATIVE INFORMATION**
The thesis will be done at SU, between the ISiR and LPTMC labs, starting Sept. 2020.

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