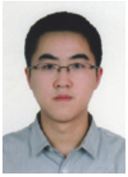
Modeling and Optimization of Biological Swarms for Medical Applications



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One of the main challenges of modern medicine is the detection of silent progression and spreading of various diseases through the human body. For instance, cancer is one of the leading causes of death because in most situations tumors appear and develop undetected by many of the screening tests or even by the immune system itself.

To overcome these challenges, we can exploit bacteria motility to engineer micro-robotic swarms capable of monitoring, detection and targeted drug delivery within the human body. In addition, with the help of synthetic biology, we can engineer bacteria with specific sensor to detect abnormal cells (e.g., therapeutic E. coli with heterologous sensors for cancer marker) and guide the swarm towards the affected regions. Towards this end, we propose a mathematical model for capturing the dynamics of a large number (or teams) of self-driven micro-robots (i.e., bacteria propelled capsules) able to swim and access small regions of the human body; this voyage takes place in a minimally-invasive manner due to micro-robots dimensions. Unlike previous modeling approaches of swarm dynamics, our mathematical formalism is able to capture not only the interactions among micro-robots, but also volume exclusion rules. This leads to a more accurate prediction of swarm dynamics and assessment of the task performance (e.g., spatial coverage measuring the detection capabilities of cancer cells, minimum time required for drug delivery).

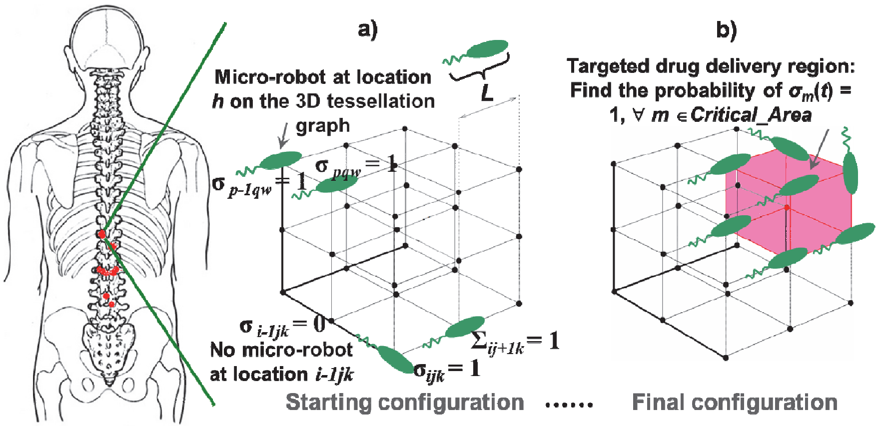

Fig. 1: The micro-robots dynamics is modeled as a collective behavior of interacting random walks in a 3D graph tessellation of space. Each node has associated a binary random variable (σ) denoting whether or not it is occupied by one micro-robot (Fig1.a). For detection and health monitoring purposes the goal is to find the time-dependent coverage. The goal of the drug delivery task is to find the probability of nodes in the diseased area (see Fig.1.b) to be occupied by micro-robots.