# Nanorobots As Cellular Assistants in Inflammatory Responses

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*abstract*

The ongoing development of molecular-scale electronics, sensors and motors could eventually lead to microscopic robots ("nanorobots") with dimensions comparable to bacteria [7]. While such robots cannot yet be fabricated, theoretical studies identify their plausible range of capabilities, including operating in fluid microenvironments of the body for medical applications [3,4]. We investigate the possibility of using nanorobots to assist inflammatory cells leaving blood vessels to repair injured tissues. The recruitment of inflammatory cells or white blood cells (which include neutrophils, lymphocytes, monocytes and mast cells) to the affected area is the first response of tissues to injury [8]. Because of their small size nanorobots could attach themselves to the surface of recruited white cells, to squeeze their way out through the walls of blood vessels and arrive at the injury site, where they can assist in the tissue repair process. Passage of cells across the blood endothelium, a process known as transmigration, is a complex mechanism involving engagement of cell surface receptors to adhesion molecules, active force exertion and dilation of the vessel walls and physical deformation of the migrating cells [9]. By attaching themselves to migrating inflammatory cells, the robots can in effect "hitch a ride" across the blood vessels, bypassing the need for a complex transmigration mechanism of their own.

A recently developed nanorobot simulator [1,2] allows investigating system-level control algorithms for these robots. The simulator uses a typical set of design parameters [4] for robots operating in a simplified fluid environment motivated by medically relevant microenvironments. The robots, whose motion is dominated by viscosity (with Reynolds numbers around $10^{-3}$), have behaviors quite different from common experience with larger, faster flows [6].

The dominance of viscosity simplifies the numerical evaluation of the fluid dynamics by ignoring inertial effects. This simplification allows focusing on overall behaviors of groups of robots, while balancing a reasonable approximation to important physical phenomena of the environment with limited computational cost of the simulator. For example, the simulator can follow the behavior of tens of robots with sizes of hundreds of nanometers over periods up to a second or so with reasonable computational effort.

We describe how this simulator can examine the response of a group of robots to chemical signals associated with the early immunological response to injury [8]. In this task, the robots must detect the signals, use gradient information to guide their motions to the source, and recognize the correct target cells to bind to achieve blood-vessel transmigration. The recruited robots must also communicate with each other to monitor their numbers and ensure a desired density of response. Such behaviors are an initial step toward a control program allowing the nanorobots to reach an injury site in appropriate numbers and assist inflammatory cells in the tissue repair process.

The simulator allows us to quantitatively evaluate the robot response in terms of reaction time, necessary power consumption and robustness. In addition, the simulator provides graphical visualization of object motions in the task environment, which is useful both to illustrate robot behaviors and identify difficulties with specific robot control algorithms. Due to the use of chemical sensors and 3D motions through the viscous fluid, this robot task is more complex than most foraging tasks studied with large scale robots [5], i.e., the physical properties of the fluid microenvironment of nanorobots provide new control challenges.

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