MULTI-AGENT NANOROBOTS DESTROYING TUMORS: NEW PERSPECTIVES ON CANCER TREATMENT

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ABSTRACT

In this article I explain and write about a simulation I have developed and run -adapted from M. Anthony Lewis and George A. Bekey's scientific paper *The Behavorial Self-Organization of Nanorobots Using Local Rules* [1], in which a group of multi-agent nanorobots, after having been injected into a human body, search for the tumor in it and, as soon as they discover it, they gather and destroy it. For some people who might not be very familiar with the evolvement of the nanotechnology, this approach may sound close to science-fiction but the way that nanorobots are currently envisaged by researchers is such that they can exhibit autonomous and collaborative behavior as multi-agent systems.

As it always happens: future is not anymore some years ahead of us. We are just living in it.

Author Keywords

Nanotecnology, Nanorobots, Multi-agent Systems, Tumor, Cancer, nanocolonies, NetLogo

INTRODUCTION: THE WORKING SCOPE

Cancer is probably one of the biggest challenges medicine is facing nowadays. Taking into account it cannot be considered a mere disease but an abnormal mutation in the cell reproduction, this fact renders this serious biological anomaly an evasive and extremely difficult-to-resolve nature.

For the last decades the use of radiotherapy and chemotherapy has been the optimal tool to eradicate the malign tumors our bodies wrongly develop. Nonetheless, bearing in mind the aggressiveness of this treatment and the amazing evolution of nanotechnology, new lines of research have been searched and launched regarding the cancer treatment and cure [5] [6].

In this article I expose a likely solution to cope with tumor removal with the help of multi-agent nanorobots, taking as reference M. Anthony Lewis and George A. Bekey's scientific article [1].

Multi-Agent systems have established their applicability in studying complex systems that involve a number of heterogeneous resources working collaboratively towards solving a common problem, despite the fact that each individual might have partial information about the problem and limited capabilities.

In parallel, nanotechnology, currently one of the most important and fast growing areas in modern science, focuses on manipulating matter with dimensions similar to the ones of biological molecules. The prefix “nano-” means a billionth, hence, when it is added in front of the word “meter” it denotes a factor of 10^{-9}, resulting in dimensions comparable to atomic diameters. Nanotechnology focuses on manipulating matter in structures with at least one dimension sized from 1 to 100 nanometers. Current advances in the domain have been receiving much attention for the past two decades, both from the academia and the industry, largely due to the fact that nanostructures exhibit unique properties and characteristics, profoundly different to the ones that have been observed at the macroscale. A plethora of applications in a wide range of fields are currently available: flexible digital screens, self-cleaning surfaces, nanoparticle comprised catalysts to carbon nanotubes acting as chemical sensors, etc. [2] However, what appears to be amongst the most promising endeavors is the development of nanotechnological constructs targeted for medical use. Nanoparticles suitable for medicine purposes, such as dendrimers, nanocrystals, polymeric micelles, lipid nanoparticles and liposomes are already being manufactured [2]. Those nanostructures exploit their inherent biological characteristics, and are based on molecular and chemical interactions to achieve the specified target.

In line with this research, already in July, 1992 two scientists of the Institute for Robotics and Intelligent Systems of the University of Southern California -M. Anthony Lewis and George A. Bekey, wrote a scientific article titled *The Behavioral Self-Organization of Nanorobots Using Local Rules*, in which the behavior of a colony of nanorobots, with the common goal of destroying malignant tissue in the brain was simulated. Each nanorobot alone had low probability of achieving its purpose; nonetheless, collectively the synergetic effect of cooperation improved meaningfully the likelihood of achieving the target. Lewis and Bekey called a cooperative group of these robots, achieving some purpose, a nanocolony [1].

The Californian researchers, incorporating rules of cooperation inspired by developmental neural biology and theoretical biology, strived to produce a simulation of a system that exhibited global cooperativity by using local distributed rules of behavior, sensing, and actuation. The target of their simulation was the removal of malignant brain tissue. For the purpose of their simulation the tumor removal goal was abstracted. The tumor was assumed to be relatively compact and the injection site of the nanorobots was presumed to be near, but not in the tumor.

To coordinate behavior in this simulation, it was essential the nanorobots communicated to each other and, in addition to this communication mechanism, each of them should have the capacity to unmask the tumor: the nanorobots were assumed to have a "tumor" detector which could differentiate between cells to be attacked and healthy cells. They should wander randomly until encounter the tumor and then act.

In Lewis and Bekey's simulation model the behavior of each individual nanorobot was defined by a set of rules, which was called its program rule set. The program rule set might change at a specific time or under a specific condition. For example, while the nanocolony was hunting tumor cells, an "eat tumor" rule set would be instantiated [1].

The shape and location of the tumor was entered by hand directly into the system, and the injection site was predetermined.

Eventually the nanorobot was only able to detect a tumor if it landed directly on a square containing a tumor element. The grid on which the nanorobots moved was considered a closed world. Therefore, reflecting boundary conditions were used.

SIMULATION DEVELOPMENT AND IMPLEMENTATION

I have developed and implemented my model simulation using NetLogo.

NetLogo is a programmable modeling environment for simulating natural and social phenomena. It was authored by Uri Wilensky in 1999 and has been in continuous development ever since at the Center for Connected Learning and Computer-Based Modeling. NetLogo is well suited for modeling complex systems developing over time. Modelers can give instructions to hundreds or thousands of "agents" all operating independently. This makes it possible to explore the connection between the micro-level behavior of individuals and the macro-level patterns that emerge from their interaction. NetLogo is written in Scala and Java and it runs on the Java virtual machine. It teaches programming concepts using agents in the form of turtles, patches, links and the observer. NetLogo was designed for multiple audiences, not only for teaching children in the education community, but also for domain experts without a programming background to model related phenomena.

The simulation model I have generated is based on Lewis and Bekey's system afore-explained, but following Gasser's approach to the design of robotic agents. Gasser simulated a number of agents whose task was to block the progress of a single "enemy" agent. The agents were required to solve the problem through cooperation, without the use of a global mechanism. Gasser divided the problem solution into six phases [3]:

1. Problem recognition.
2. Enlisting allies -gathering partners.
3. Forming a coordination framework instantiating a set of behavior expectation and commitments.
4. Mid-game problem -moving toward a goal configuration.
5. Endgame problem solving. -following a small set of rules on toward a known solution.
6. Termination -recognition of a goal configuration.

In my simulation the initial scenario encompasses a group of x nanorobots, injected inside a human body, with a certain value regarding their energy threshold[1]. As it can be noticed in the screenshot below attached -Fig. 1, besides the nanorobots, there is a red square which symbolizes the tumor:

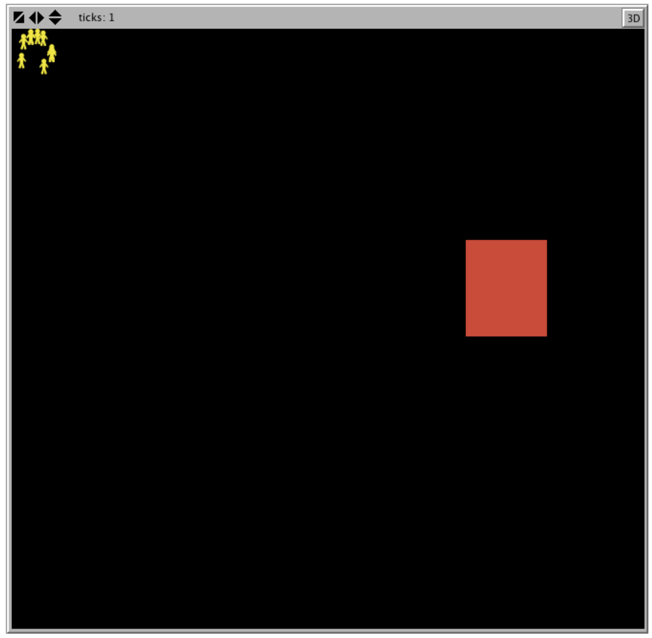

Fig. 1

At the left hand of the simulation grid there is dashboard from which the simulation can be reinitialized (setup bottom) and launched (go bottom); parameters such as number of nanorobots -turtles in the NetLog terminology- can be monitored; there is a switcher to show the nanorobots' level of energy; and there is a slider as well to control the number of nanorobots running in the simulation, being 20 the maximum amount I have defined.

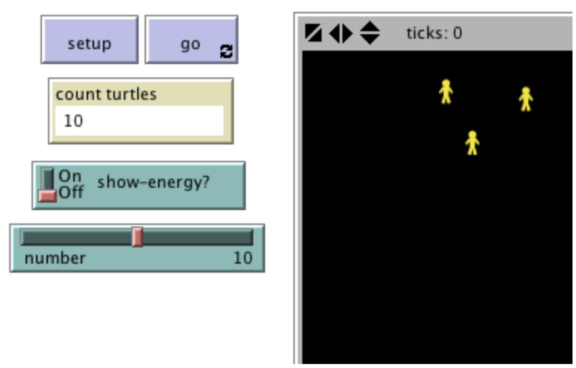

Fig. 2

[1] Energy threshold refers to the amount of energy a nanorobot enjoys before committing to its tasks of attacking and destroying a tumor. When a nanorobot's energy threshold equals to or is less than a certain amount, it biodegrades itself and disappears.

The same as in Lewis and Bekey's simulation, I have predefined the shape and location of the tumor.

The process is the following: upon clicking on the button "go", the nanorobots begin wandering around looking for the tumor. As soon as one of them discovers the tumor, it communicates the news to the rest, the exact location, and all of them gather in front of the tumor - Gasser's phases 1, 2, and 3:

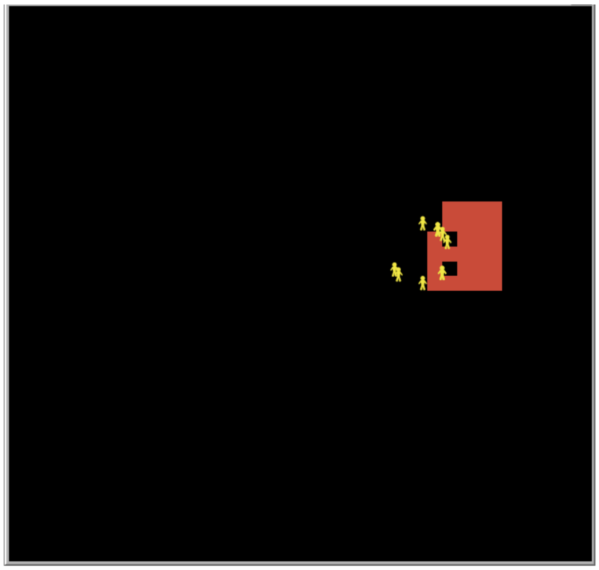

Fig. 3

And they begin attacking and destroying it:

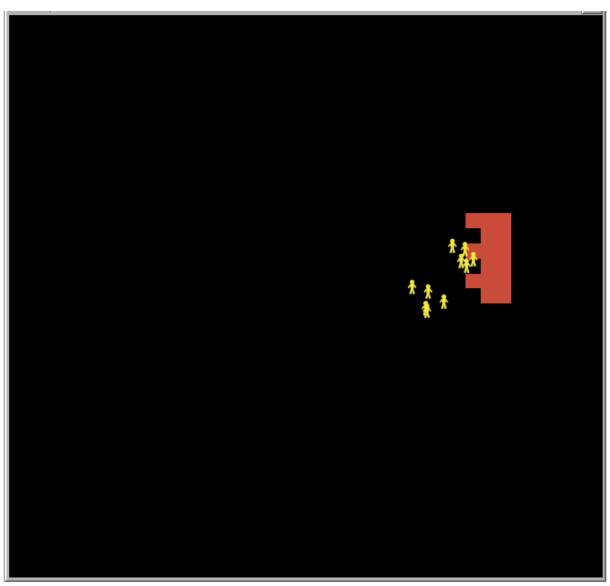

Fig. 4

Every single time one of the nanorobots manages to destroy a piece of the tumor, all of them gather again and they begin their attack from their initial point since they consider once the tumor membrane is broken at that point, that is the weakest and easiest gap to get in and to keep on their labor of destroying the cancer -Gasser's phases 4 and 5.

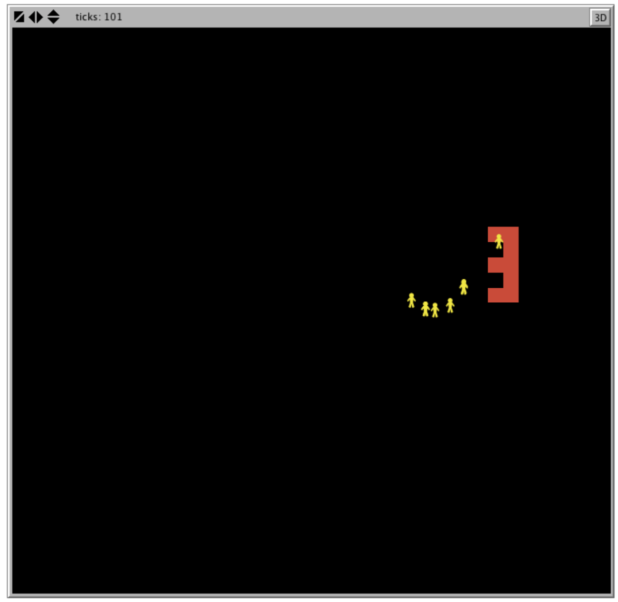

Fig. 5

Unlike Lewis and Bekey's and Gasser's models, I would like to highlight that in the simulation I have developed, at the end of their task, nanorobots exhibit an **artificial intelligent behavior**: those nanorobots, which have been more exposed to the tumor because they have been more active fighting and destroying it, biodegrade themselves as not only their exposition to a malign tissue has been higher than the rest, but also their level of energy after the effort has diminished more and, in the event that a new tumor might appear, they would not be adequate individuals to carry out the required fight.

In the screenshot below -Fig. 6- six nanorobots remain in the area, just monitoring the likely appearance and growth of new tumors (Gasser's pahse 6). They can linger in the human body since their composition and structure are fully compatible with the human nature:

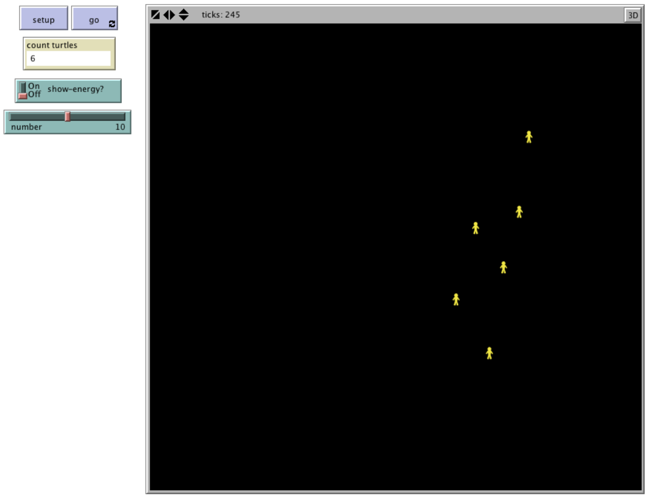

Fig. 6

In order to check out the performance of the system, I have executed the simulation five times with the following different criteria:

Scenario 1

- Number of nanorobots = 10
- Energy threshold = -90
- Final result:
    - Tumor completely removed.
    - Number of ticks[2] = 711.
    - Remaining number of nanorobots = 8

Scenario 2

- Number of nanorobots = 15
- Energy threshold = -50
- Final result:
    - Tumor completely removed.
    - Number of ticks = 615.
    - Remaining number of nanorobots = 7

Scenario 3

- Number of nanorobots = 20
- Energy threshold = -30
- Final result:
    - Tumor completely removed.
    - Number of ticks = 706.
    - Remaining number of nanorobots = 8

Scenario 4

- Number of nanorobots = 8
- Energy threshold = -110
- Final result:
    - Tumor completely removed.
    - Number of ticks = 1,610.
    - Remaining number of nanorobots = 6

Scenario 5

- Number of nanorobots = 5
- Energy threshold = -150
- Final result:
    - Tumor completely removed.
    - Number of ticks = 1,672.
    - Remaining number of nanorobots = 3

FINDINGS

Considering the results afore-mentioned, it can be stated that the success rate of the group of nanorobots is complete regarding the tumor removal. Sometimes it may take them more time -i.e., ticks- to locate and destroy the tumor, but eventually they always manage to do it.

The model I have developed meets the main four requirements of multi-agent systems: stigmergy, self-organization, emergence, and positive feedback.

[2] A tick means a variation -in this case, movement- in the state of the group of nanorobots. For instance, if the tick counter shows a value of 750 after the removal of the tumor, it means the group of nanorobots has moved 750 times until destroying the tumor.

Considering s**tigmergy,** as a mechanism of indirect coordination between agents or actions, in the sense that it leads to the spontaneous emergence of coherent systematic activity, I can state that definitely there is this property in my model; namely, when the first nanorobot launches the attack to destroy the tumor, this action leads and coordinates the attitude of the rest of nanorobots, which get together in order to attack and destroy the tumor as well. Therefore, not only stigmergy but there are **self-organization and collaborative behavior** likewise.

The feature **positive feedback** is also present: with their attack and destroying action nanorobots are removing an alien malign element in the human body.

And finally there is **emergence**, in the sense that this is a process whereby larger patterns and regularities arise through interactions among simpler entities, that themselves do not exhibit such properties.

Regarding the future work, from my point of view the most important challenge regarding the use of nanorobots to cure cancer is: how could nanorobots fight and succeed when there is metastasis in a patient with cancer? In the simulation I have developed the tumor is perfectly defined and static but many times this is not the case.

As a conclusion, a last thought with respect to this kind of multi-agent simulation exercise: due to the very nature of medical research, which requires lengthy periods of time and adherence to strict protocols, before any new developments are encompassed, computer simulations can offer a great advantage towards accelerating both the basic and applied research processes to the cure of serious diseases or biological anomalies such as cancer.

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