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COMPARISON OF THREE MODELS OF MELANOMA GROWTH BASED ON SPH SOLVER, PARTICLE AUTOMATA (PAM) AND CELLULAR AUTOMATA (CA) PARADIGMS

Bartosz Minch
Filip Koperski
Wojciech Matuła
Marta Panuszewska

Department of Computer Science
AGH University of Science and Technology
Al. Mickiewicza 30
Kraków, 30-059, POLAND

ABSTRACT

We compare three discrete computer models of skin cancer proliferation based on smoothed particle dynamics (SPH), particle automata (PAM) and cellular automata (CA). The main contribution of this work are the development of SPH, PAM and CA melanoma models and the attempt to synchronize them in such a way, that the three will produce similar growth scenarios. We have developed and examined two basic models: the first one with tumor penetrating the healthy tissue and the second one where tumor evolves on the surface of healthy skin. We obtained very good qualitative agreement with realistic melanoma growth scenarios.

1 INTRODUCTION

As show recent reports on the global cancer burden over 14 million new cancer cases were diagnosed and above 8 million people died in 2012 worldwide. More than a half of those occurred in economically developing countries. The expectations are even more alarming by predicting 21.7 million new cancer cases to be diagnosed and 13 million deaths in 2030. Even though a tremendous effort was spent on understanding cancerogenesis and developing an effective anticancer therapies, in general, the neoplasm remains resistant to all currently used drugs. The purpose of this work is to create a novel model of tumor dynamics that uses the smoothed particle dynamics (SPH) method as a numerical engine. The main reason of that, is to check if this method can perform better than the other discrete two-phase models such as particle automata model (PAM) (Wcisło et al., 2009) and 3-D version of cellular automata Lee-Rieger-Bartha cancer model (Lee et al., 2006). We have tested these three approaches on the layout (container with healthy particles and tumor developing on the surface), which mimics the proliferation of skin cancer - melanoma.

2 MODELS OF MELANOMA PROGRESSION

Unlike in PAM model, where both cancerous and healthy tissues were made of particles interacting with each other via spring harmonic forces (Wcisło et al., 2009), in SPH model we assume that biological tissues are represented by a viscous fluids. Their mechanical interactions are described by the Navier-Stokes equations. The healthy tissue serves as a basis in which tumor develops. Each „cancerous" SPH and PAM particle has its life cycle consisting of 3 stages: proliferation, quiescent and necrosis. In proliferation stage, if a cell is well oxygenated it can replicate due to the process of mitosis and divide into two new proliferative particles (with a basic amount of oxygen). Apart from oxygen concentration, we assume two other control parameters. Namely, the cell lifetime and the states of neighboring cells. We assume also, that the quiescent cell is deprived the reproduction ability and its oxygen consumption rate is minimal.

In the state of necrosis the particle is removed. Consequently, in CA model all these assumptions are represented by the CA rules. All three models are simulated in the layout representing simplified multi-layer model of skin (see the Figure) (Łoś et al., 2017).

3 RESULTS

We have conducted series of simulations of melanoma dynamics by using the three (SPH, PAM and CA) methods. We used SPH model for simulating the beginning stage of cancer progression examining the effect of specific parameters such as difference in viscosity between tumor and tissue cells and the ratio of oxygen consumption. Surprisingly, as shown in Figure 1, even in the smallest spatio-temporal scale we observe clear differences between the growth scenarios for various parameters choice. For greater scales of tumor dynamics (PAM, CA) the growth scenario was more stable. We try to find similar tumor behaviors regardless of model choice. Our results show, that it is not a trivial problem and it challenges modeling in subject of cancer research.

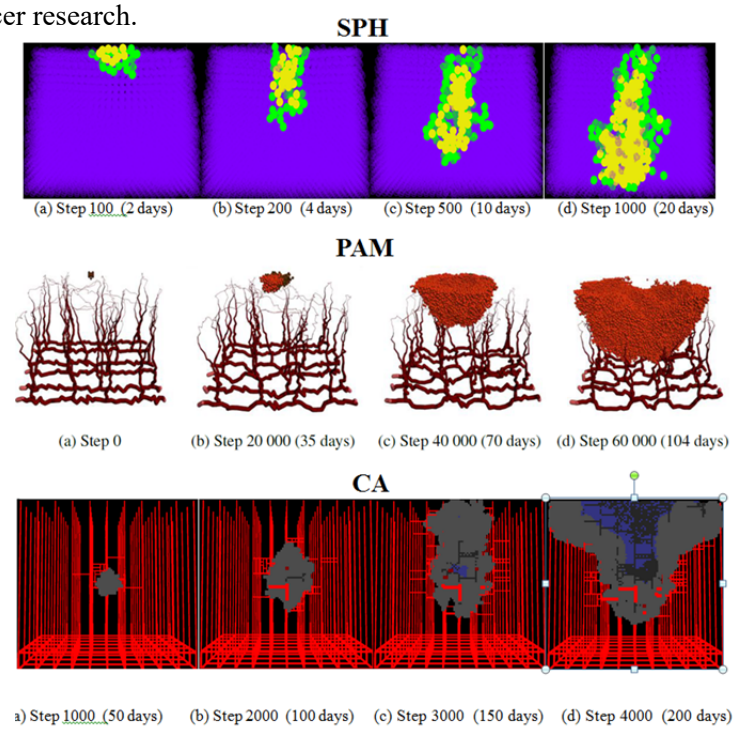

Figure 1: The snapshot from 3-D melanoma simulations by using three various models in various spatio-temporal scales. Sizes of the computational boxes in SPH, PAM and CA models are radically different (SPH 0.5x05x0.5 mm, PAM 5x5x4 mm, CA 20x20x20 mm).

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