Modeling tissues: numerical simulations and continuum mechanics

Part II - Numerical Simulations

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Abstract

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In this second part of the course, we will go over the various methods used to simulate tissues.

We will start by showing a rough taxonomy of cell models in general and we'll briefly discuss the general framework of agent-based modelling. Then we will see in some details the three big classes of tissue modeling strategies:

1. Lattice based models rely on a descretized space to simulate cells. Each cell here occupies a set of pixels, and the physics of the system is solved locally. Those model are adapted to rapid assessment of tissue dynamics with mixed cell types, proliferation and differentiation models.

2. Cell-center based models. Here each cell is an individual sphere (maybe deformable) interacting in free space with it's immediate neighbours. This class of model is adapted to problems in cancer biology, involving high cell numbers.

3. Vertex-based models. Here cells are delinated by polygons or polyhedron, and the phyics is applied at the polygon vertices. This class of models is widely used for morphogenesis modeling.

A rough taxonomy of tissue models

Population dynamics

- Only concerned with $N(t)$

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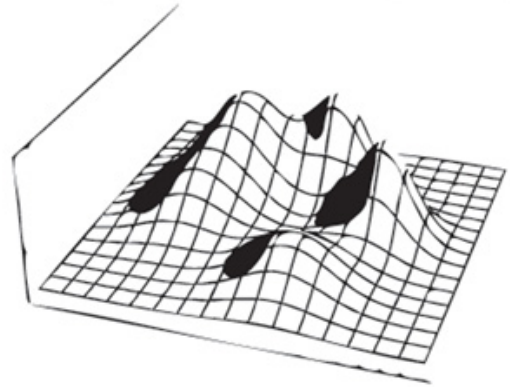
- Focus on **signaling** and division / death rates
- Main use is **mathematical oncology**: predict cancer growth in response to treatment

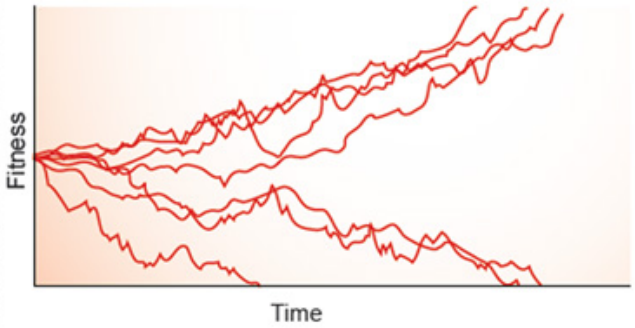
Fitness landscapes

Random field/sequence-structure/phenotype-fitness

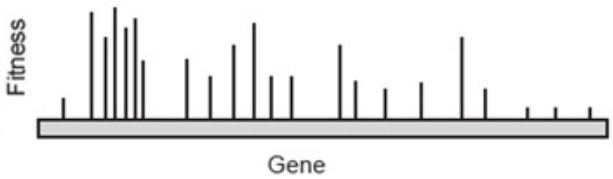


Empirical studies

Evolution experiments



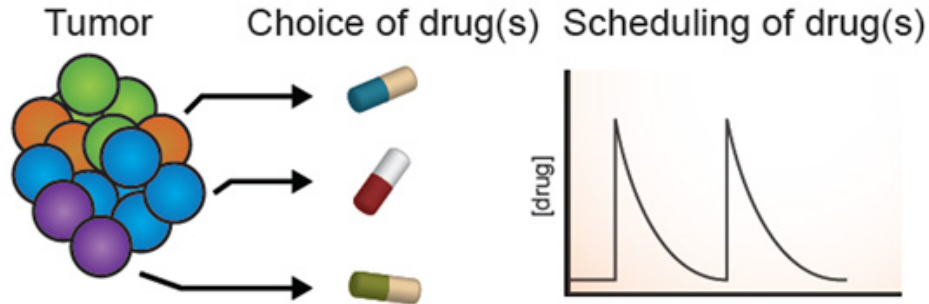
Mutagenesis/saturation analyses



Mathematical models

Stochastic models (Moran, Wright-Fisher, branching process, Kolmogorov equations, etc)
Deterministic models (ODE, PDE, evolutionary dynamics, etc)
Combinatorial optimization/mathematical programming
Optimal control theory

Rational drug scheduling/combinations design



Agent based modelling

Lattice based models

Game of life

The Graner Glazier Hogeweg model

The Modified Metropolis Algorithm

Cellular Potts Model Hamiltonian

Extending the CPM: the example of Chemotaxis

Existing Software

Cells as spheres

The work of Dirk Drasdo et al.

JF. Joanny

PhysiCell (Mathematical Oncology)

Cells as polygons

Topology of epithelium

Voronoï tessalation (Honda et al.)

Topology changes in 2D & 3D

Active vertex model

Rosettes

Mechanical Model formulations

Work by Farhadifar et al.

Work by Lisa Manning et al.

Towards rheological models

Existing implementations

Zhao, Boyang, Michael T. Hemann, and Douglas A. Lauffenburger. 2016. "Modeling Tumor Clonal Evolution for Drug Combinations Design." *Trends Cancer* 2 (3): 144–58. https://doi.org/10.1016/j.trecan.2016.02.001.