Cellular Automata Modeling of Tumor Growth Using Object-Oriented Methods

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Subject of modeling: tumor

Tumor is a mass of abnormal tissue with:
• no purposeful function
• tendency to independent and unrestrained growth
• the potential to invade and destroy neighboring tissues and create metastases
Cancer: some facts and figures

Risk factors:
- Smoking (90% of lung cancer)
- Air pollution
- Radon gas
- Genetic factor

Biological properties of tumor cells
- Acquisition of self-sufficiency in growth signals
- Loss of sensitivity to anti-growth signals
- Loss of capacity for apoptosis
- Loss of capacity for senescence, leading to limitless replicative potential (immortality)
- Acquisition of sustained angiogenesis, allowing the tumor to grow beyond the limitations of passive nutrient diffusion
- Acquisition of ability to invade neighbouring tissues
- Acquisition of ability to build metastases at distant sites
- Loss of capacity to repair genetic errors, leading to an increased mutation rate (genomic instability)
Method: Cellular Automata

Cellular automaton (pl.: cellular automata) is a discrete model studied in computability theory, mathematics, theoretical biology and microstructure modeling.

Model consists of:
- Grid of cells
- Finite number of states

Advantages:
- Describing complex community’s behavior using behavior rules for each its member
- In case of cancer modelling CA can give the geometry of tumour
- Verbal model of cells’ behavior is exactly embodied in CA rules

Cellular automata using OOP methods

Objects’ states

Class objects

Cells

Normal cell

Tumor cell

Necrotic cell

Methods:
- Apoptosis
- Division
- Migration
- Mutation
Cellular automata using OOP methods

**Class objects**

- Cells
  - Normal cell
  - Tumor cell
  - Necrotic cell

**Objects’ states**

**Attributes:**
- Position (x,y)
- Lifetime
- Mitosis period
- Rates of consumption
- Capacity to mutation
- Capacity to repair genetic errors
- Replicative potential

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**Cellular Automata Life Cycle**

- Rates of consumptions
  - PDE
  - Nutrient concentrations
  - New cells’ densities
  - Cellular activities
  - Probabilities

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Biomedical techniques department
Cells division, death and movement in cellular automata model

Cellular automata probabilities

\[ P_{\text{tumor}} = \exp \left( \frac{- \ln(1-P_{\text{tumor}})}{\tau_{\text{tumor}}} \right) \]

\[ P_{\text{host}} = 1 - \exp \left( \frac{- \ln(1-P_{\text{host}})}{\tau_{\text{host}}} \right) \]

\[ P_{\text{mig}} = 1 - \exp \left( \frac{- \ln(1-P_{\text{mig}})}{\tau_{\text{mig}}} \right) \]

Tumor cell replacement

Random migration of tumor cell

Tumor cell division

Mother cell

H, T

Host cell replacement

Results in simple tissue

Model parameters

- Lifetime: 5-7 days
- Mitosis period: 16-24 hours
- Main resource is glucose
- Pathological cells consume the resource in 10 times more than normal cells

On tumor shape influence:

- The relative rates of tumor cells nutrient consumption
- The original tissue density
- Host cells rate of consumption

Tumour cells' distribution after 30 iterations
Results of modeling in complex tissue

Normal and pathological cells’ distribution

Nutrient distribution. Colour represents relative concentration

Distribution of normal (right) and tumour (left) cells

Modeling using OOP

Initial cells’ distribution

- 10 tumor cells
- 1000 normal cells
- 1000 necrotic cells
- Square domain 100x100 CA cells
- Lifetime is 5 cycles for normal and 20 cycles for tumor cells
Modeling using OOP

Cells’ distribution after 35 cycles
- Totally 2048 cells
- 531 tumor cells
- 369 normal cells
- 1142 necrotic cells
- Two tumor focuses

Modeling using OOP

Cells’ distribution after 50 cycles
- Totally 3837 cells
- 2785 tumor cells
- 216 normal cells
- 512 necrotic cells
- Tumor focuses united
Results

Normal tissue growth (is linear)

Unlimited resource and loss of capacity to apoptosis lead to exponential tumor growth

Conclusions

• Cellular automata modeling conception perfectly coordinates with biological description of tumor growth.
• Object-oriented programming allows to build a flexible model built on cellular automata conception, and to complicate the automata rules without total model rebuilding.
• Futhermore model development may include building 3D-model, adding immune cells and limiting resources, adding chemotherapy influences ect.
References

2. Ershov U.A., Kotin V.V., Kirillova S.K., Kabiso R.K. Cancer Diseases Revealing on the Basis of Tumor Growth Kinetic Analysis and Increase of Efficiency. Biomedical electronics, №10, 2005
5. Georgiady S.G., Kotlyarov P.M. Computer-aided tomography signals of diffuse lung diseases