Agent based models: spatial environments

CSCS 530 - Marisa Eisenberg

Types of ABM environments

- Non-spatial (or at least, not explicitly spatial)
- Network topologies (may be thought of as spatial or not)
  - E.g. subway networks vs. contact networks
- Explicitly spatial environments
  - Grids
  - 2D or 3D space
  - Mapping - have agents move through a real-world-based environment

Grids

- We have seen several examples of this (cellular automata, the Shelling model, forest fire model, etc.)
- A classic example along these lines that uses the environment in an active way is **Sugarscape**
  (slides mostly borrowed from Lynette Shaw)

Sugarscape Model

- Classic, very well-known model of wealth distribution developed in the mid-1990s
- Presented by Joshua Epstein and Robert Axtell in their classic book, *Growing Artificial Societies*
- Begins with a very simple model then explores an extremely wide-range of substantively interesting variations
- Many more variations have been developed since

Classic Sugarscape: Environment

- Agents exist on a square-lattice known as “Sugarscape” w/ individual lattice positions that generate a generic resource called “sugar”
- **Patch variables**
  - Current sugar level, max sugar capacity
- **Patch methods**
  - Patches regenerate sugar according to some function G_{alpha} where alpha = units of sugar grown back in one time step, up to max capacity

Classic Sugarscape: Agents

- **Agent variables**
  - Position: x,y coordinates on the Sugarscape
  - Sugar level: how much sugar agent currently has (no limit)
  - Metabolism (m): how many units of sugar it “burns” per time step
  - Vision (v): how many lattice positions away an agent can “look” for sugar

Classic Sugarscape: Agent actions

- Movement (M):

  1. Look out v number of positions in NWSE directions (no diagonal!)

  2. Move to nearest, unoccupied position w/the most sugar

  3. Collect all sugar on that position

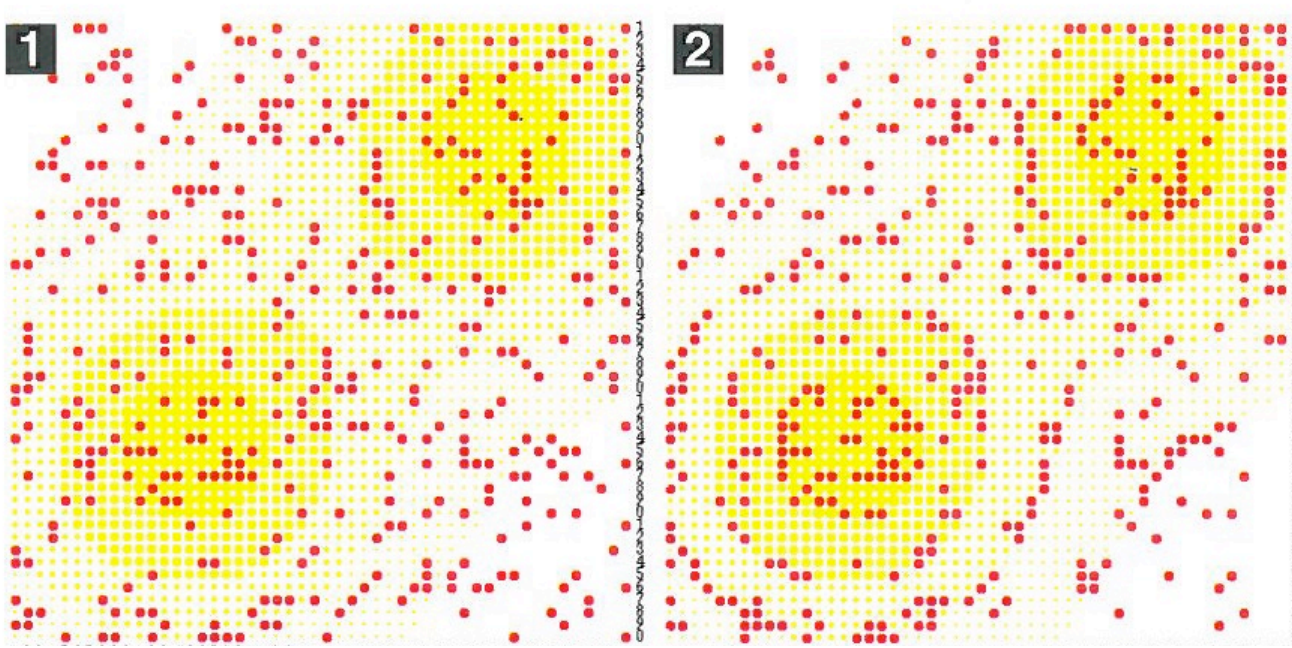
Classic Sugarscape: Agent actions

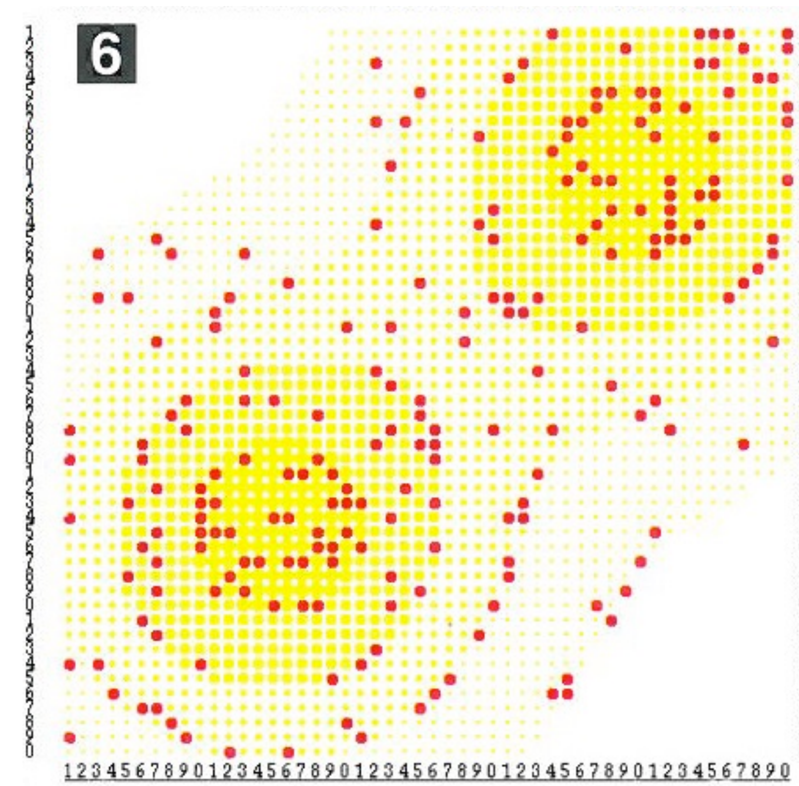
- Metabolize:
    1. Decrement sugar level by m units
    2. If current sugar level < 0, die

Baseline model for Sugarscape

- Baseline Model:
  - Random initialization of agents for v, m, and initial sugar level
  - Set alpha = infinity

Animation II-1. Societal Evolution under Rules ({G_∞}, {M}) from a Random Initial Distribution of Agents



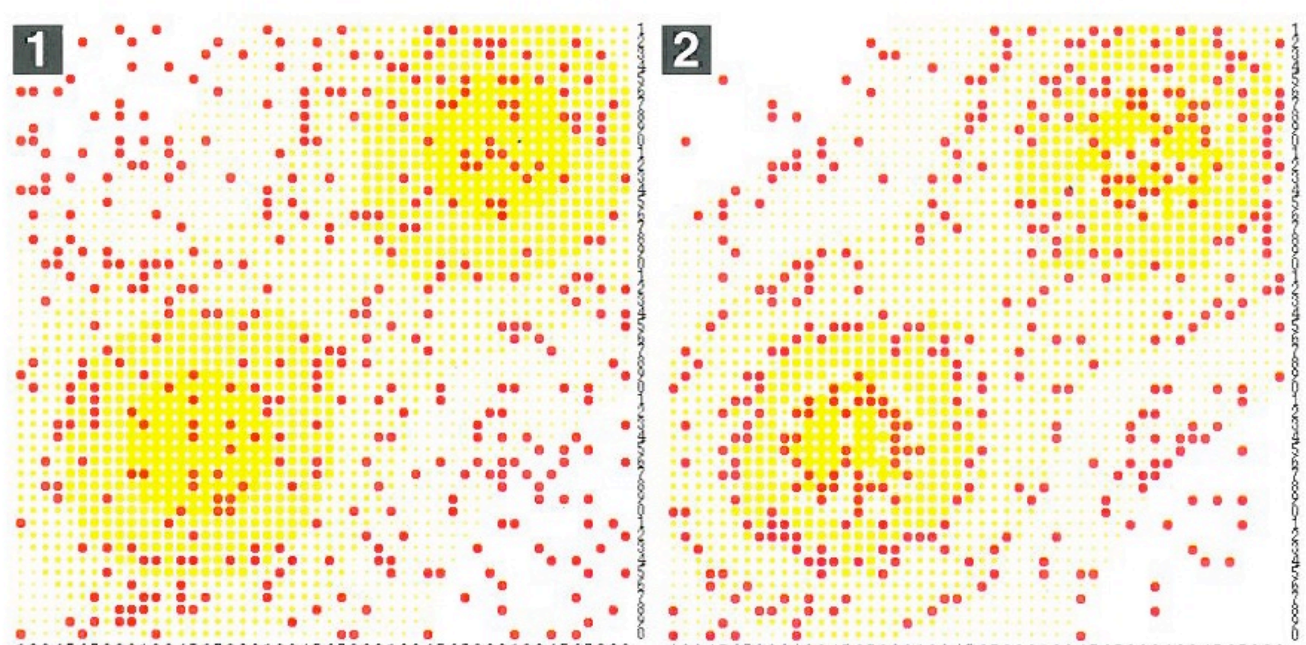


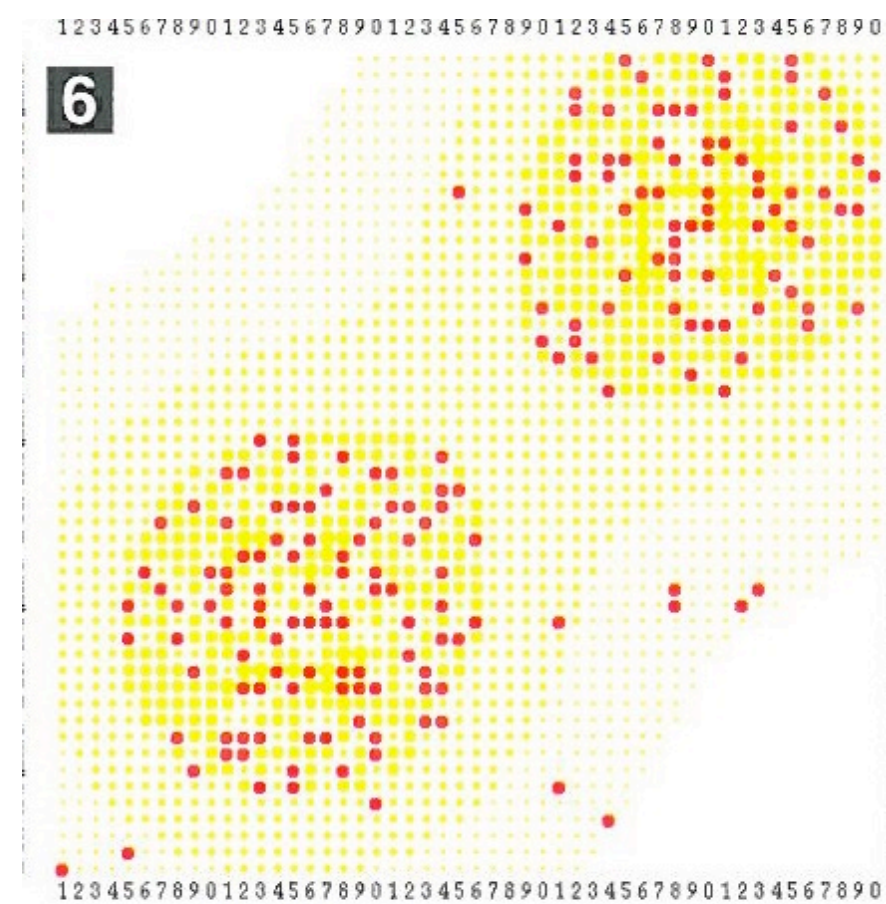
Figures from *Growing Artificial Societies*

Baseline model for Sugarscape

- Baseline Model:
    - Random initialization of agents for v, m, and initial sugar level
    - Set alpha = 1

Animation II-2. Societal Evolution under Rules ({G_1}, {M}) from a Random Initial Distribution of Agents





Figures from *Growing Artificial Societies*

Wealth Distributions in Sugarscape

- In baseline model, no replacement for agents that die. Living agents accumulate sugar indefinitely —> no stationary wealth distribution

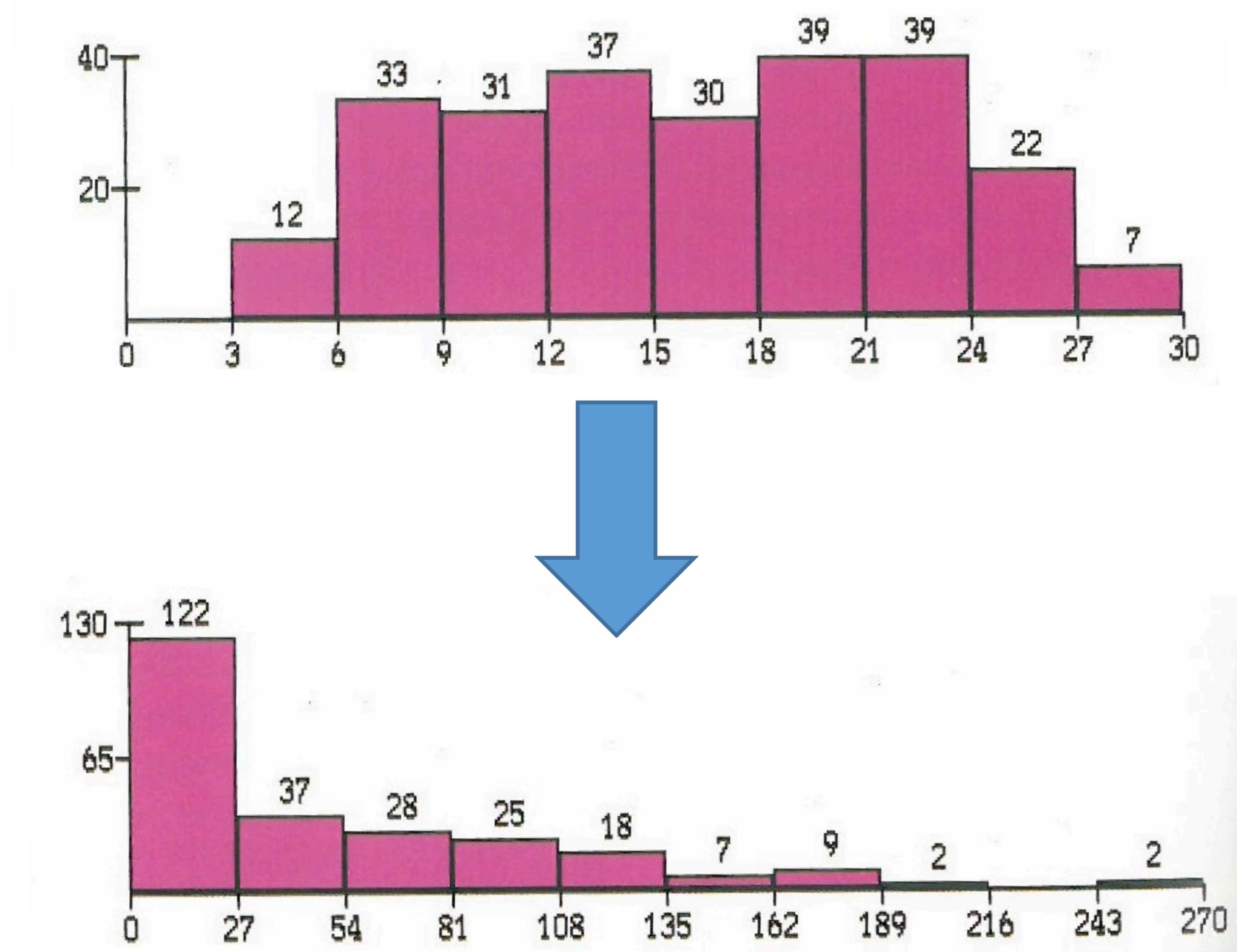
- Variant: Add Replacement Rule

    - Each agent gets a max achievable age drawn from [a,b]. Die after that age (or before if $sugar < 0$)

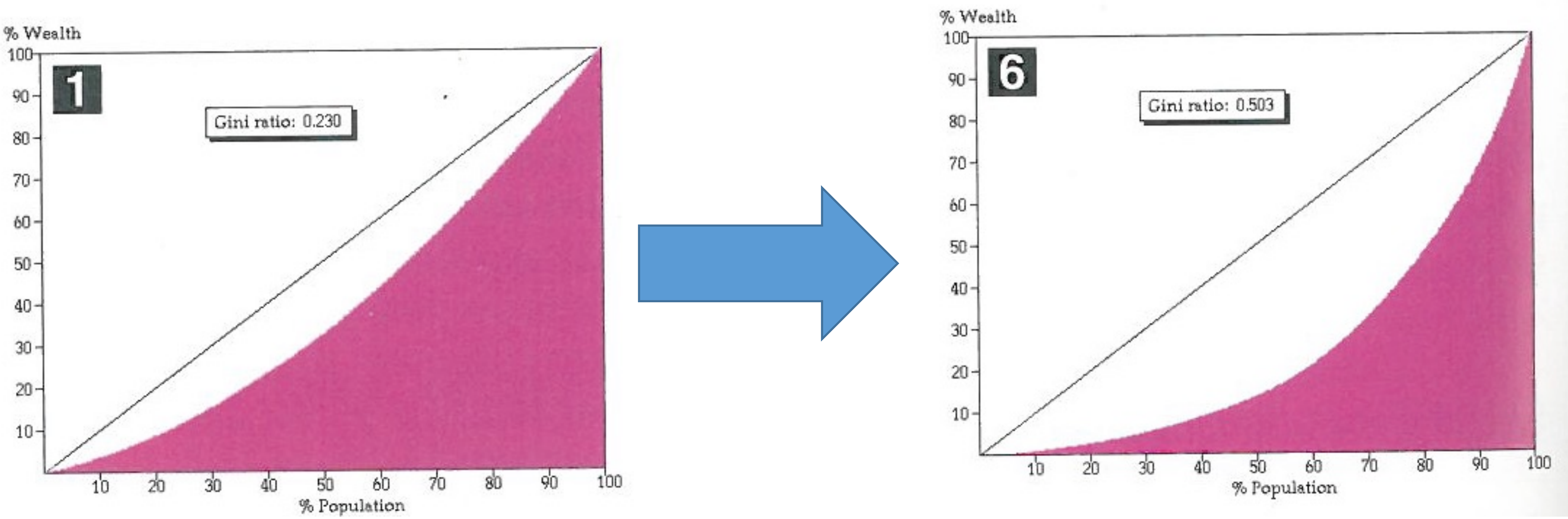
    - When agent dies, replace w/a randomly initialized (including position) agent

Emergence of a skewed wealth distribution

Animation II-3. Wealth Histogram Evolution under Rules ({$\mathbf{G}_1$}, {**M**, $\mathbf{R}_{[60,100]}$}) from a Random Initial Distribution of Agents



Emergence of inequality



Demonstrates how empirically reminiscent patterns of inequality can emerge from a set of simple rules + environmental and actor heterogeneity

Migration variations

- Alter initial random distribution of agents to add more "structure" in starting position

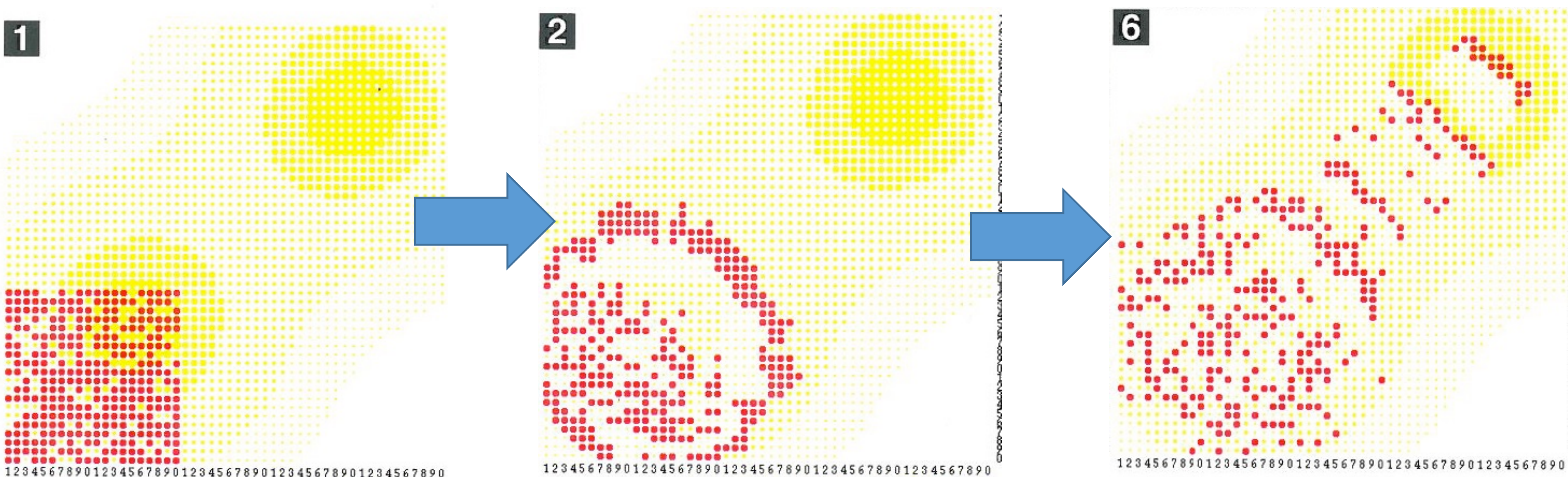
- Seasonal Migration

  - Introduce spatial and temporal patterning in alpha by creating an "equator" in space and "seasons" of higher-lower alphas in the two regions

  - Note: only environmental changes. No changes to movement/agent rules

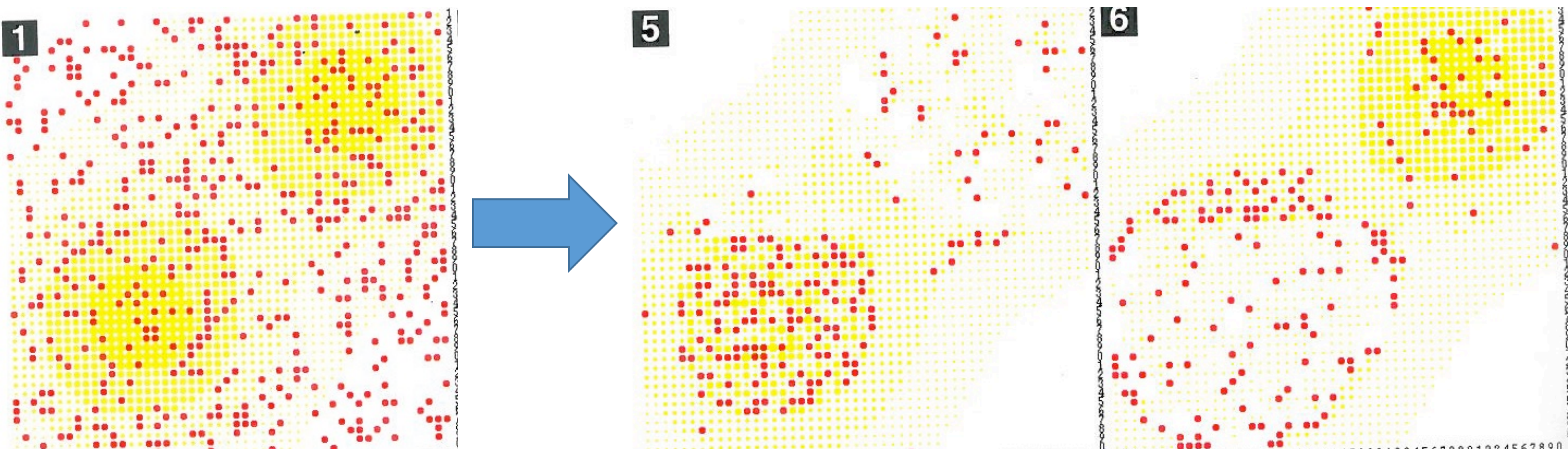
Migration

- Diagonal pattern of movement



Seasonal Migrations

- Migration + emergence of “hibernators” and “migrators”



The World of Sugarscape Elaborations

- Though the baseline model is extremely simple, a wide number of elaborations and variations have been developed to explore a host of other issues
    - Social networks
    - Sexual reproduction
    - Cultural change
    - War and conflict
    - Inheritance and wealth
    - Disease

Sugar and Spice: a Market Dynamics Elaboration

- This elaboration begins with the introduction of a second resource to the environment, “spice”
- Agents now have both a sugar level and a spice level with a corresponding m for each. Die if either level < 0
- Movement now changes to be driven by a “Welfare” (W) function

Sugar and Spice: Agent Welfare Function

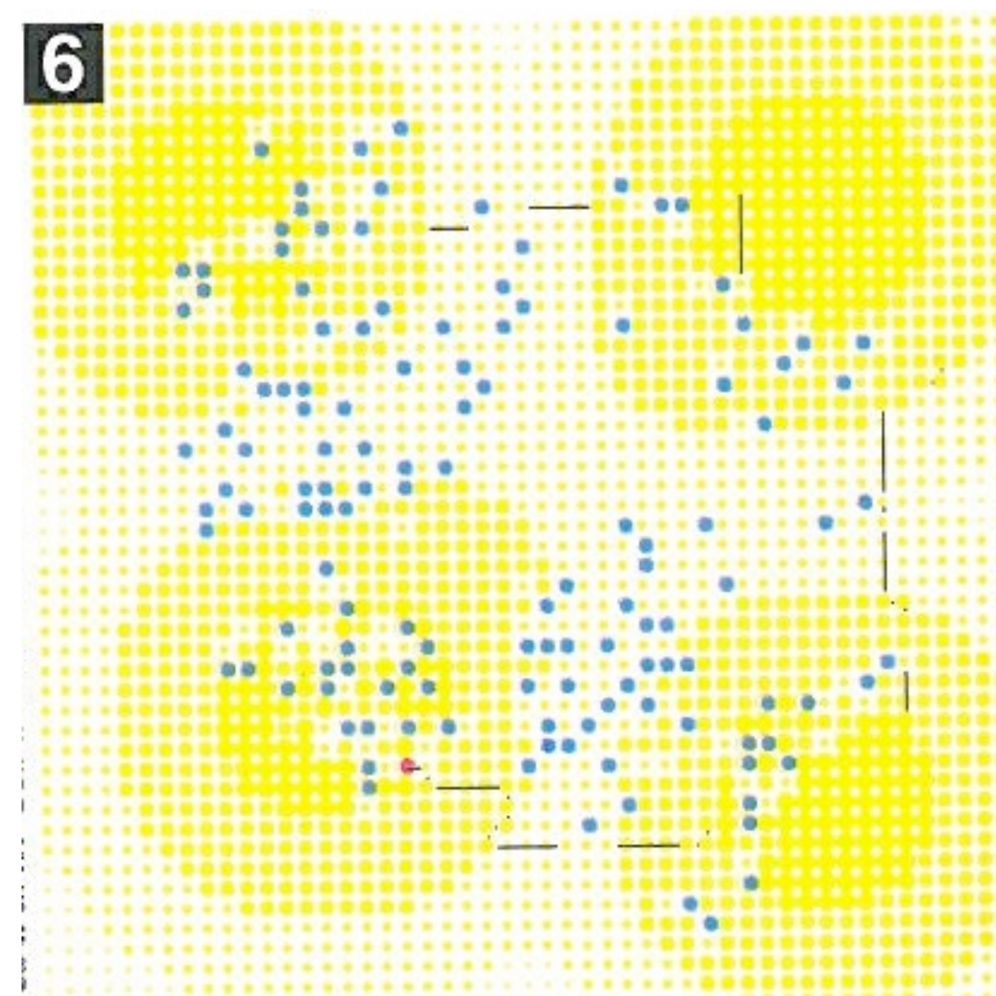
- 1 = Sugar, 2 = Spice
- $m_T = m_1 + m_2.$

  $W(w_1, w_2) = w_1^{m_1/m_T} w_2^{m_2/m_T},$

- Movement Rule Change:
- Replace “unoccupied position with maximum sugar level” with “unoccupied position maximum welfare increase”

Sugar and Spice: No Trade

- Oscillating movements between Sugar and Spice piles
- Lower carrying capacity than 1 commodity scenario



Sugar and Spice: Trade Rules

- With 2 commodities, can now allow for decentralized trade between agents
- Marginal Rate of Substitution (MRS) $\dfrac{\frac{w_2}{m_2}}{\frac{w_1}{m_1}}$

	$MRS_A > MRS_B$		$MRS_A < MRS_B$	
Action	A	B	A	B
Buys	sugar	spice	spice	sugar
Sells	spice	sugar	sugar	spice

Sugarscape

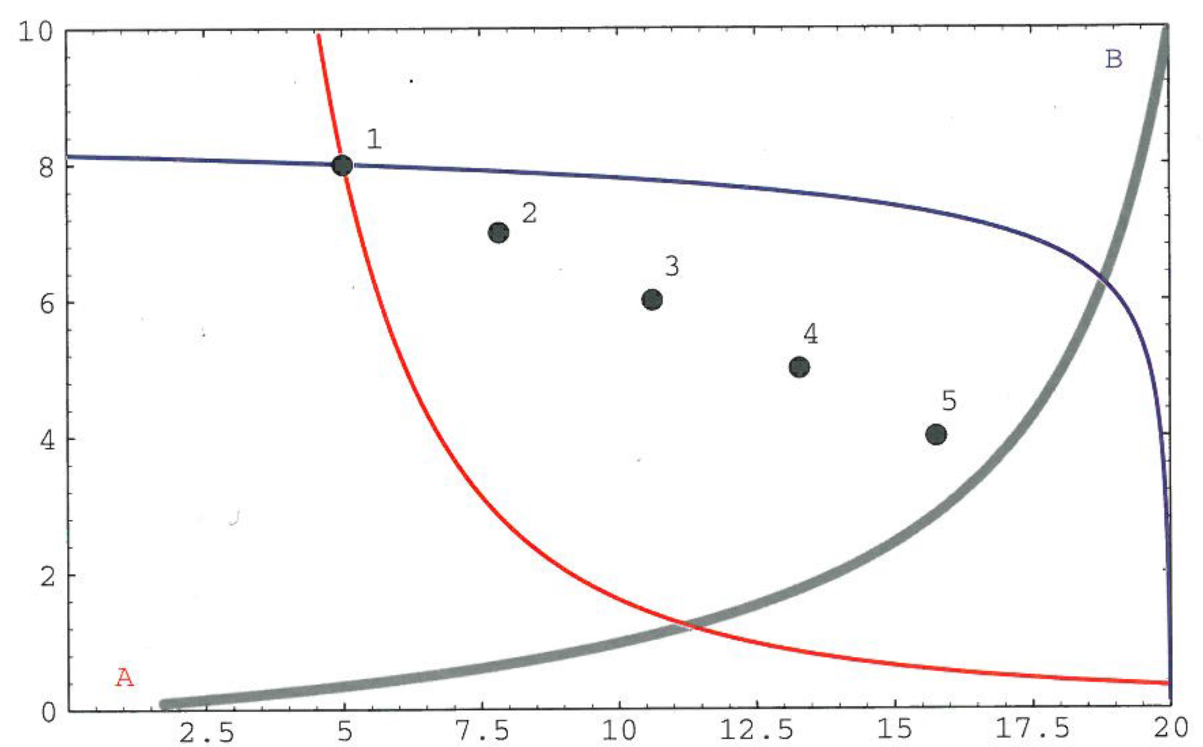
Agent trade rule **T**:

- Agent and neighbor compute their *MRS*s; if these are equal then end, else continue;
- The direction of exchange is as follows: spice flows from the agent with the higher *MRS* to the agent with the lower *MRS* while sugar goes in the opposite direction;
- The geometric mean of the two *MRS*s is calculated—this will serve as the price, p;
- The quantities to be exchanged are as follows: if $p > 1$ then p units of spice for 1 unit of sugar; if $p < 1$ then $1/p$ units of sugar for 1 unit of spice;
- If this trade will (a) make both agents better off (increases the welfare of both agents), and (b) not cause the agents' *MRS*s to cross over one another, then the trade is made and return to start, else end.

Sugarscape

- Local Pareto Optimality
- Can show that these rules for exchange and price formation, played out multiple times in a bargaining dyad, achieves a local Pareto optimum

Figure IV-2. Edgeworth Box Representation of Two Agents Trading according to Rule **T**



Sugarscape

- Decentralized trading can lead to a stable, average trade price w/o the need for a central "auctioneer"
- Also, increases carrying capacity of system

Figure IV-3. Typical Time Series for Average Trade Price under Rule System ({$\mathbf{G}_1$}, {**M**, **T**})

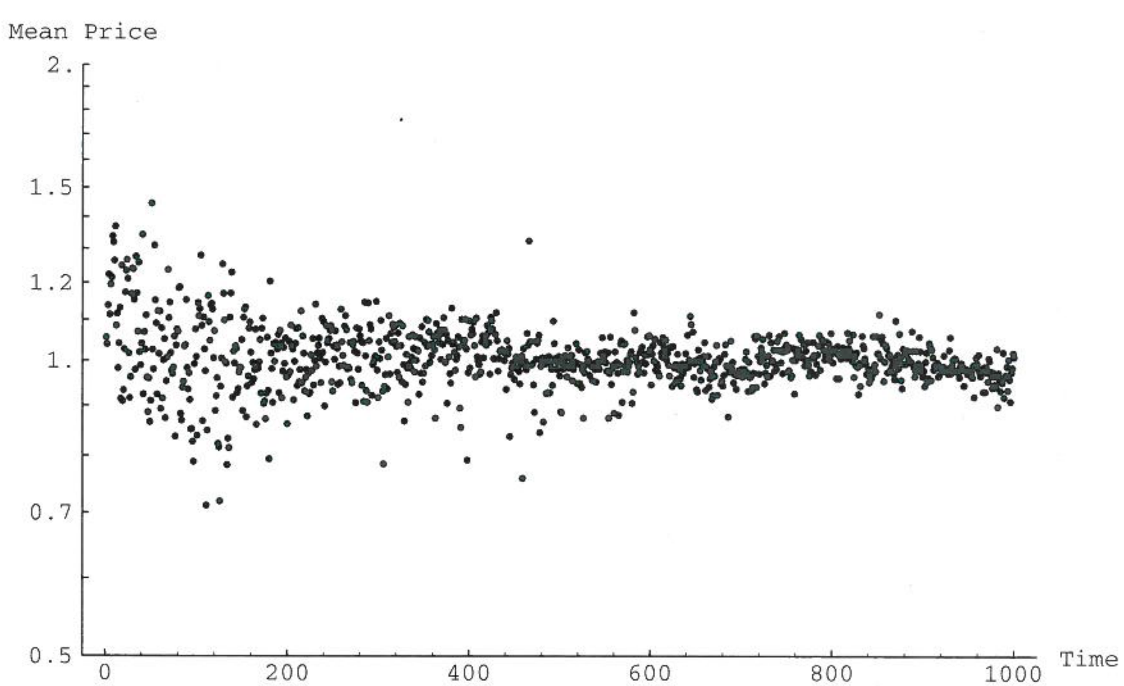
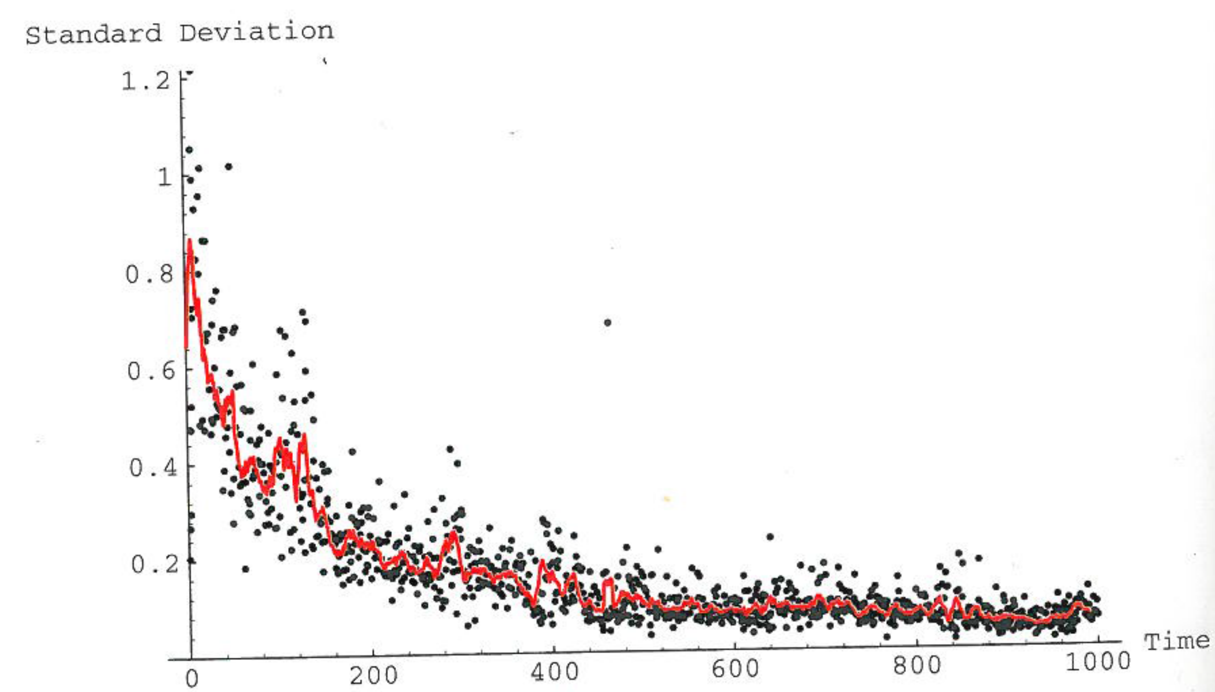


Figure IV-5. Typical Time Series for the Standard Deviation in the Logarithm of Average Trade Price under Rule System ({$\mathbf{G}_1$}, {**M**, **T**})



Sugarscape extensions

- Horizontal inequality
- Ability to get into “Far From Equilibrium Economics”
- Price variance strongly impacted by agent vision
- Local efficiency, Global inefficiency

2D or 3D space

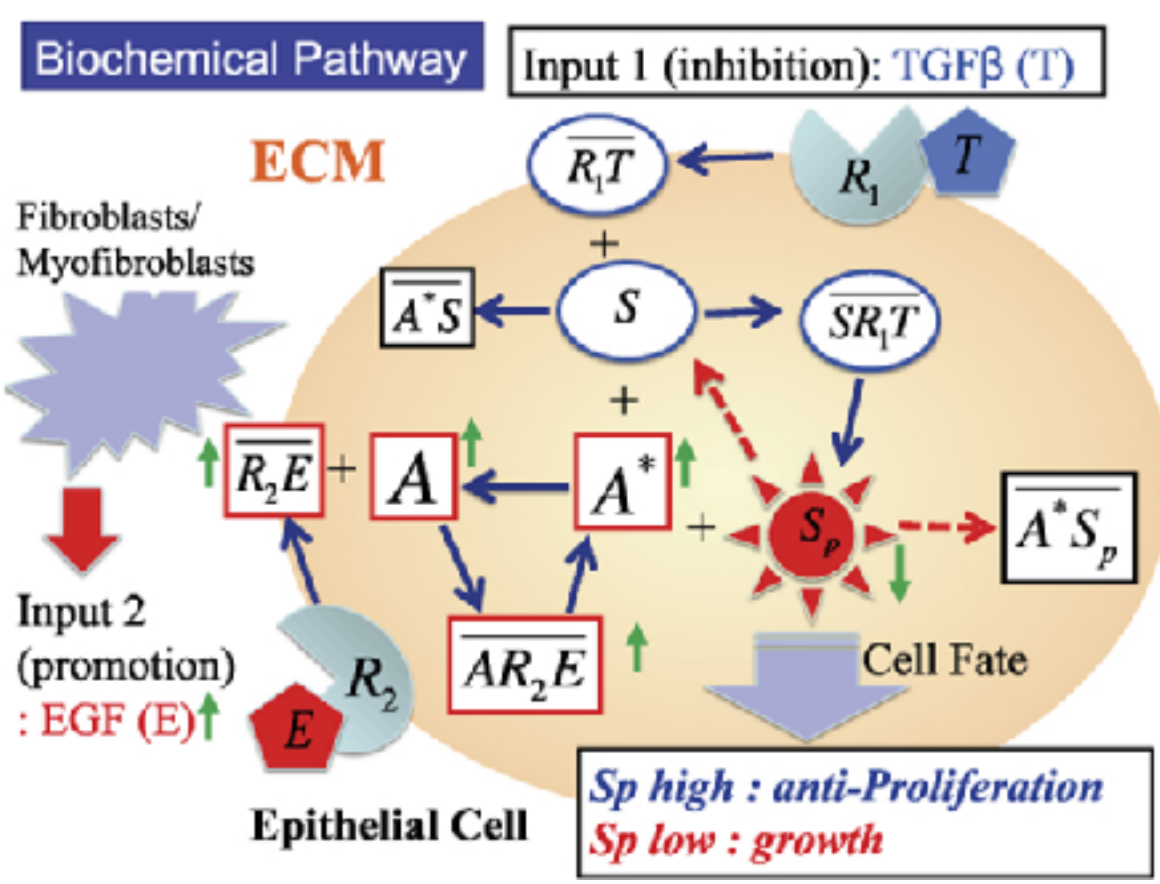
- 2D space
  - Abstract 2D spaces with arbitrary setups but not on an explicit grid (e.g. movement is decided based on a distribution not on a grid)
  - Imaging data (e.g. MRI, microscopy imaging)
  - Map data
- 3D space
  - Often used for flocking simulations (e.g. Boids)
  - Also for modeling complex biological or physical domains (e.g. cellular environments, etc.)

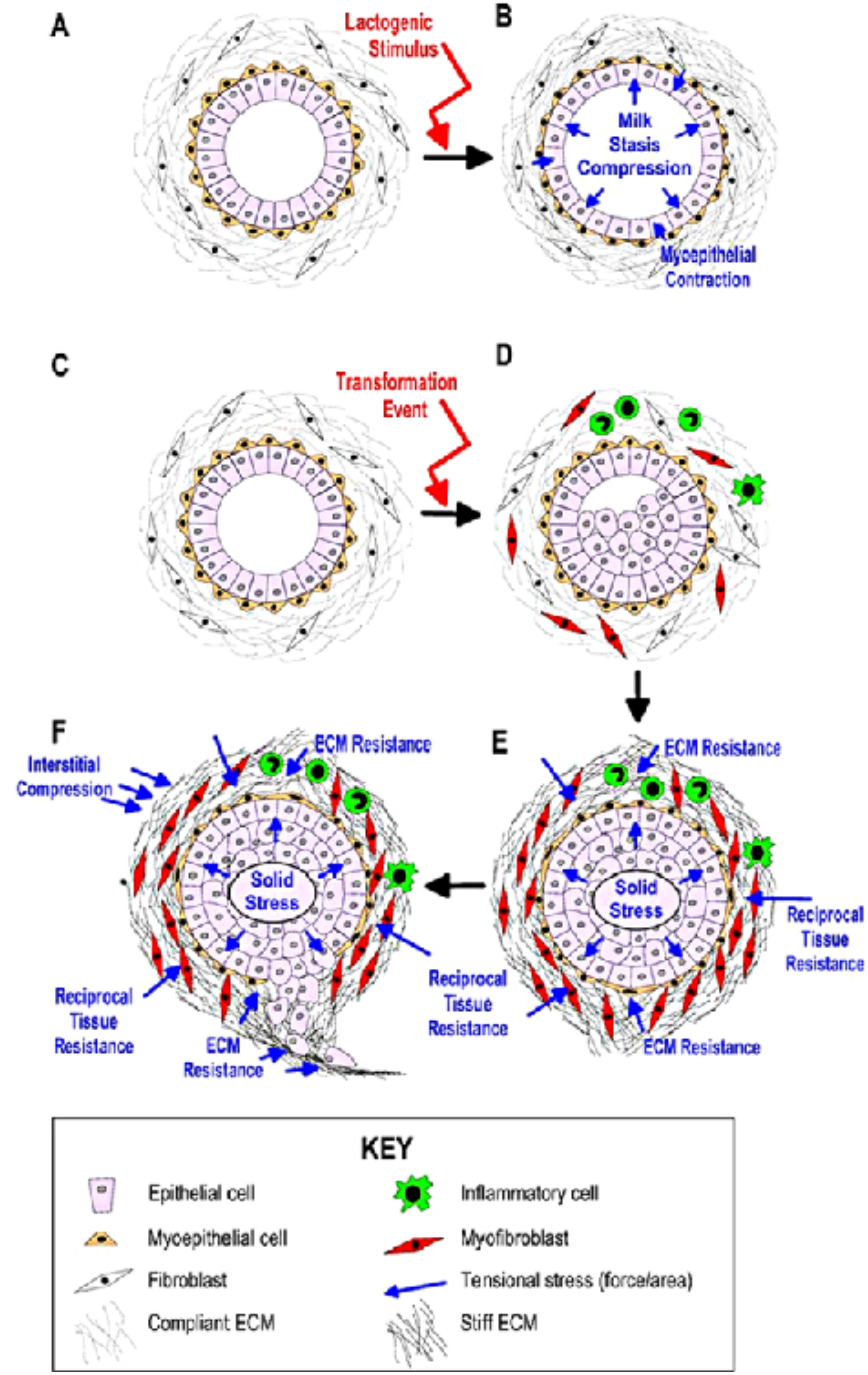
Abstract 2D & 3D space

- We have worked with several examples of this in 2D space (e.g. ants, rabbits/foxes)
- Complex environments can be generated

Example: hybrid model of breast cancer dynamics

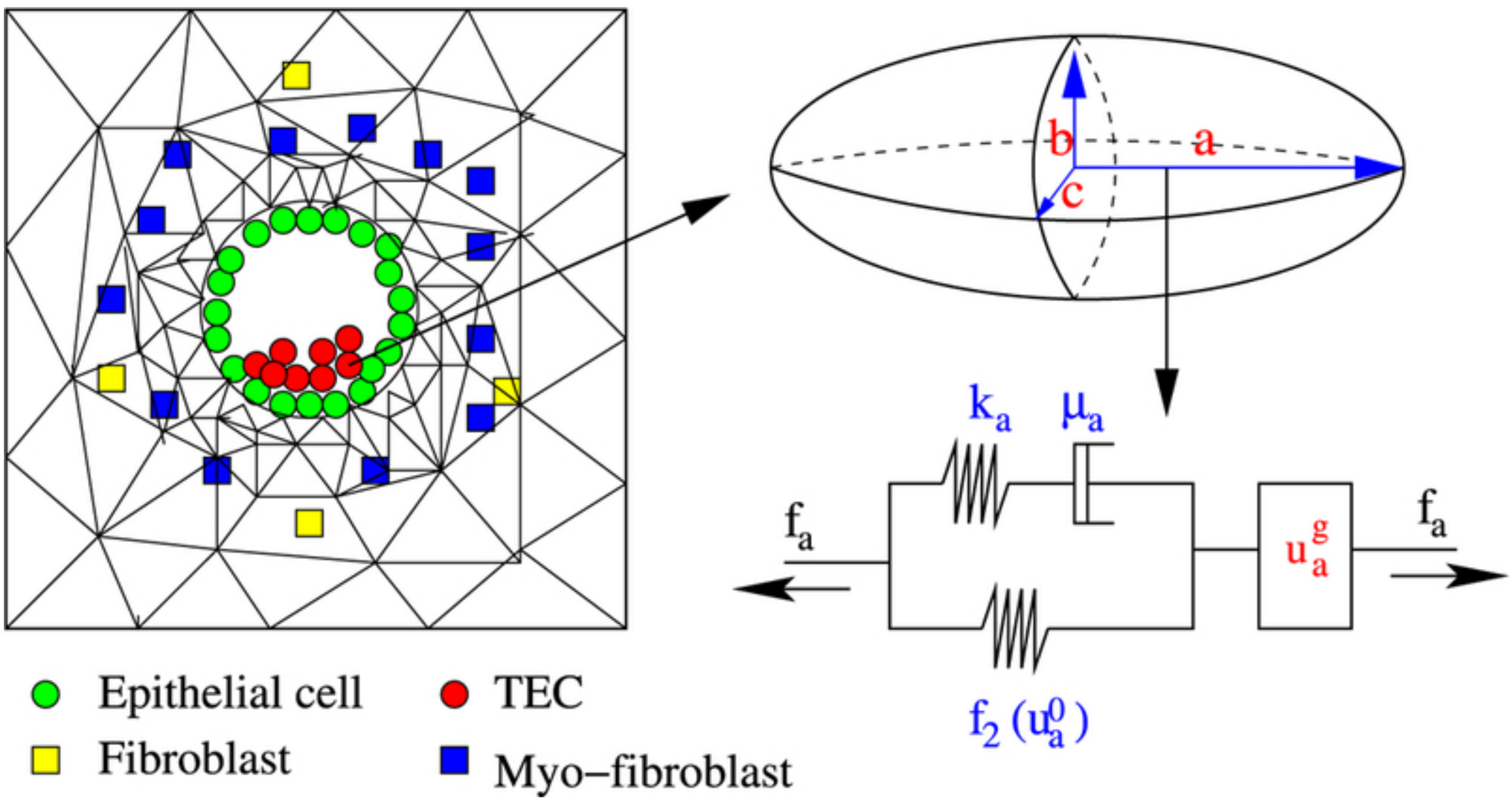
- Transformation from normal ducts to solid tumor in breast cancer





Kim & Friedman - https://www.ncbi.nlm.nih.gov/pubmed/23292359

Cells as agents within the duct



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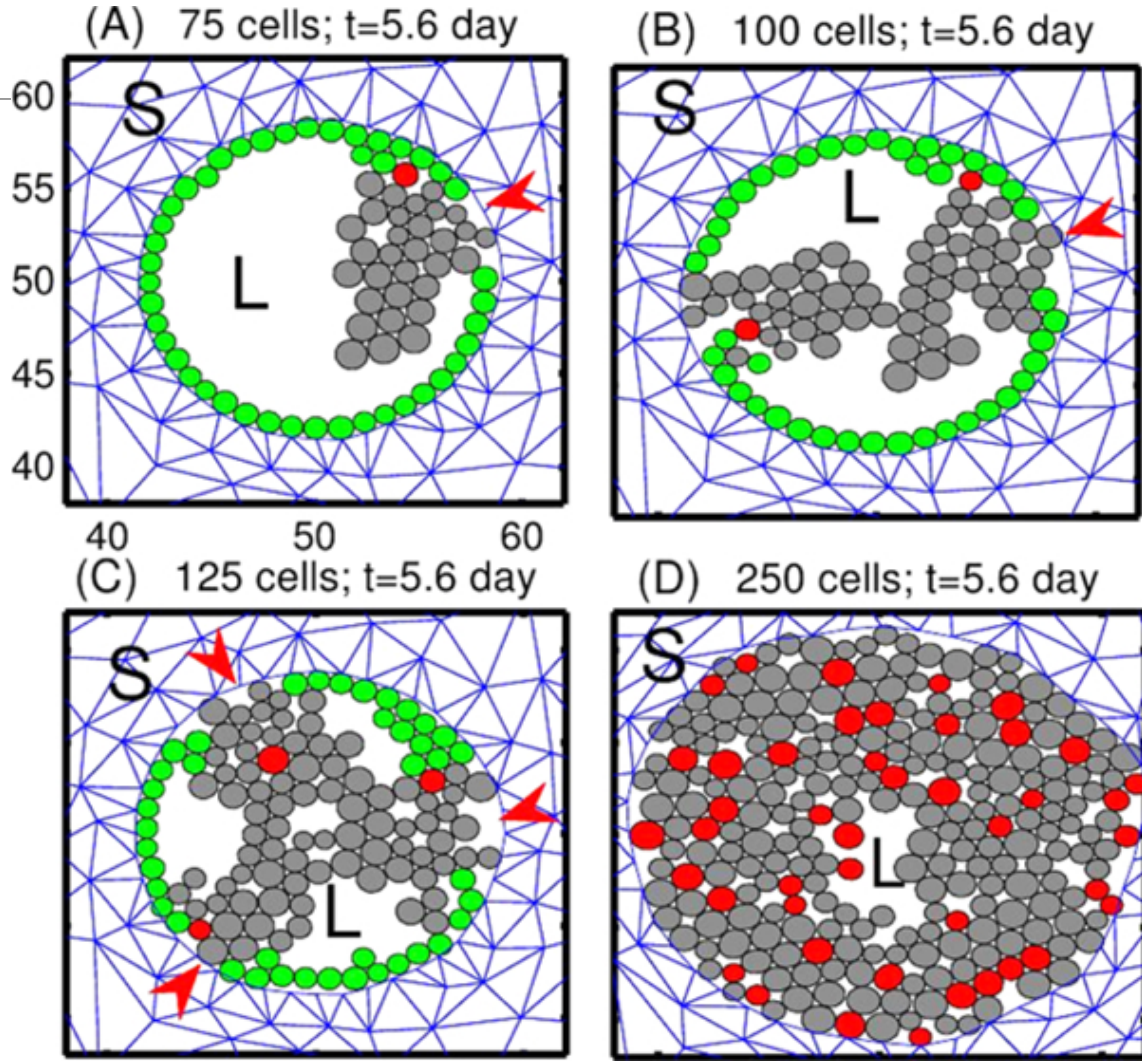

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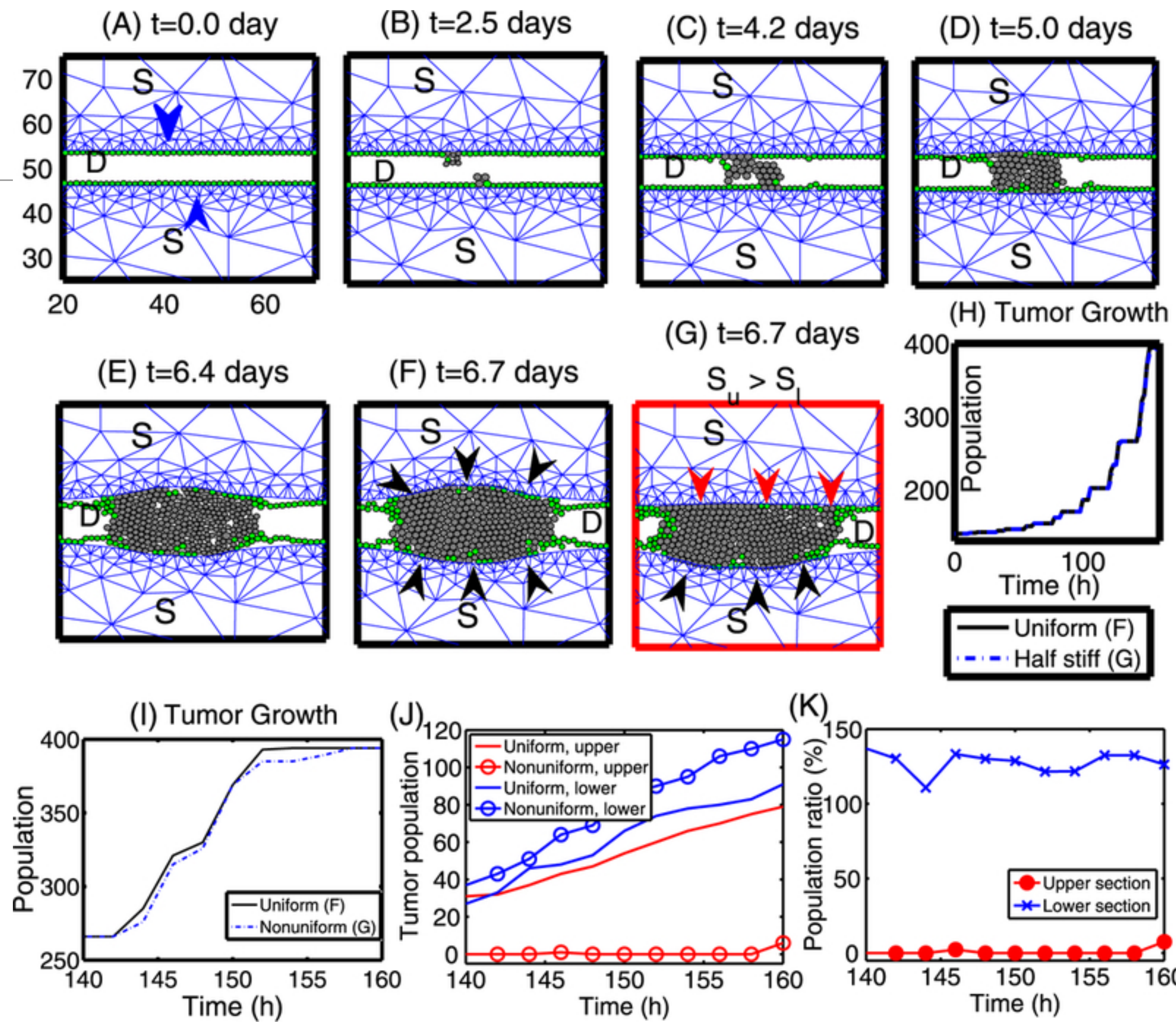
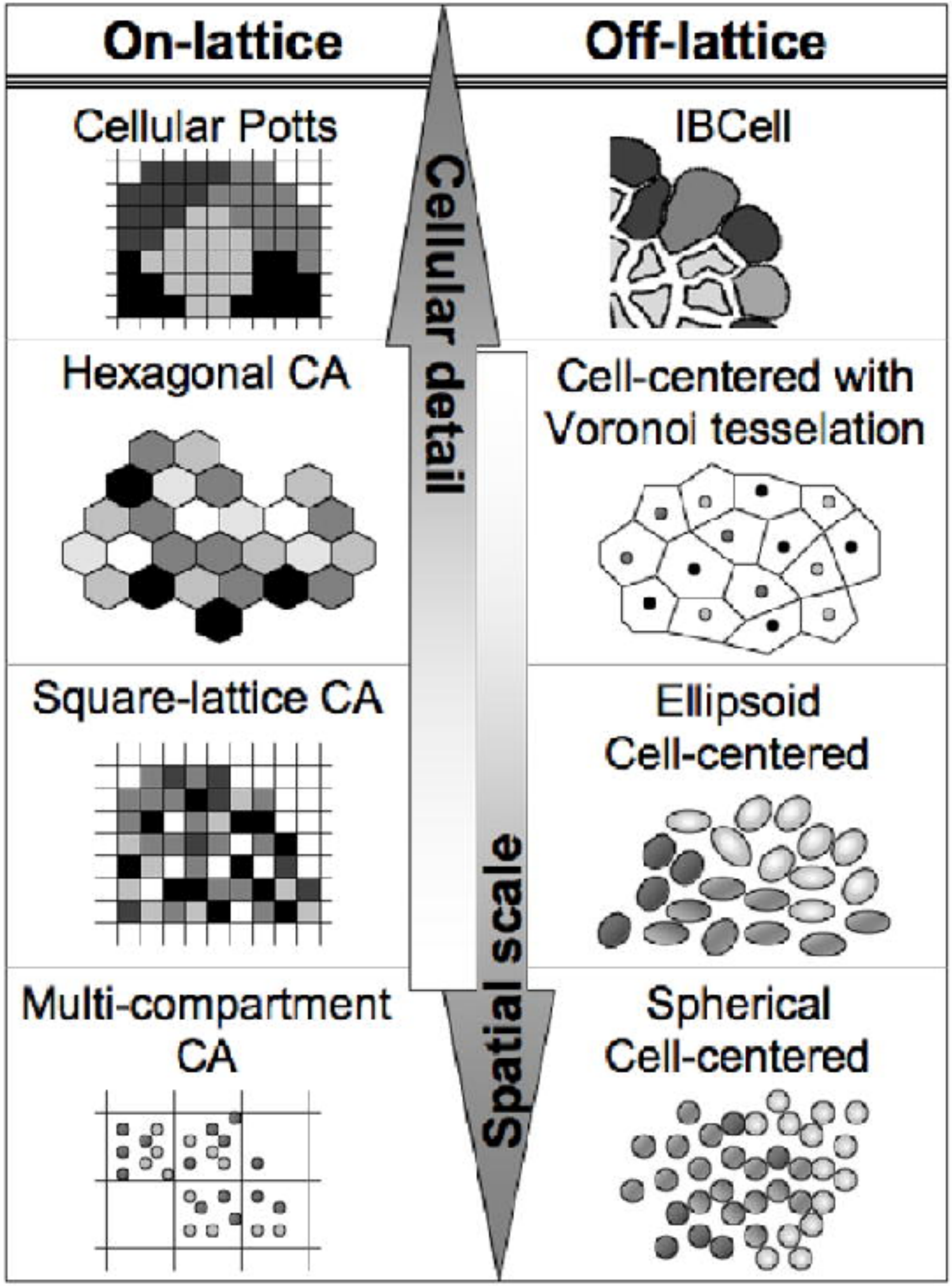
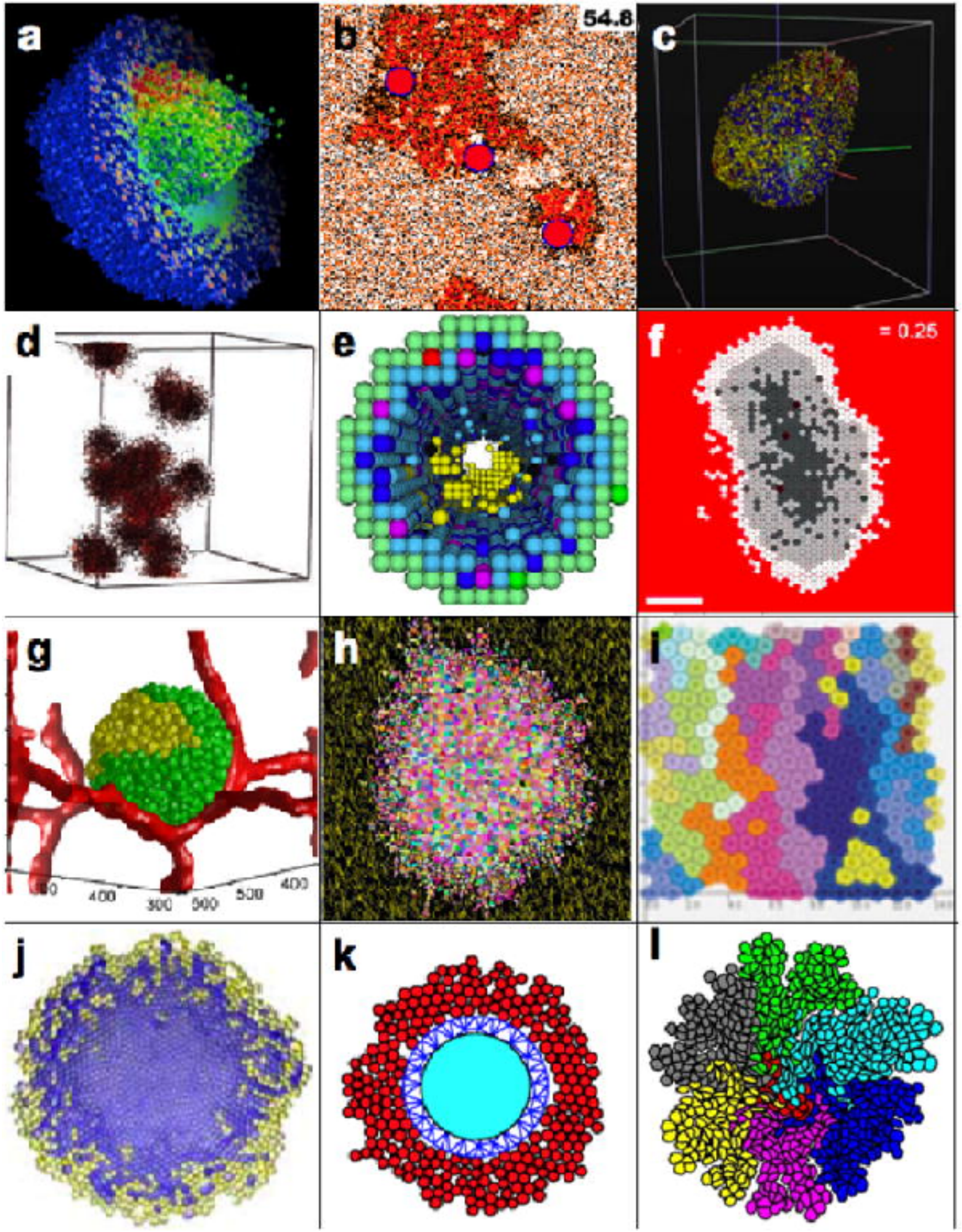


(A) t=0.0 day
(B) t=2.5 days
(C) t=4.2 days
(D) t=5.0 days
70
60
50
40
30
20
40
60
S
D
(E) t=6.4 days
(F) t=6.7 days
(G) t=6.7 days
S_u > S_l
(H) Tumor Growth
Population
Time (h)
400
300
200
0
100
Uniform (F)
Half stiff (G)
(I) Tumor Growth
Population
Time (h)
Uniform (F)
Nonuniform (G)
(J)
Tumor population
Uniform, upper
Nonuniform, upper
Uniform, lower
Nonuniform, lower
(K)
Population ratio (%)
Upper section
Lower section

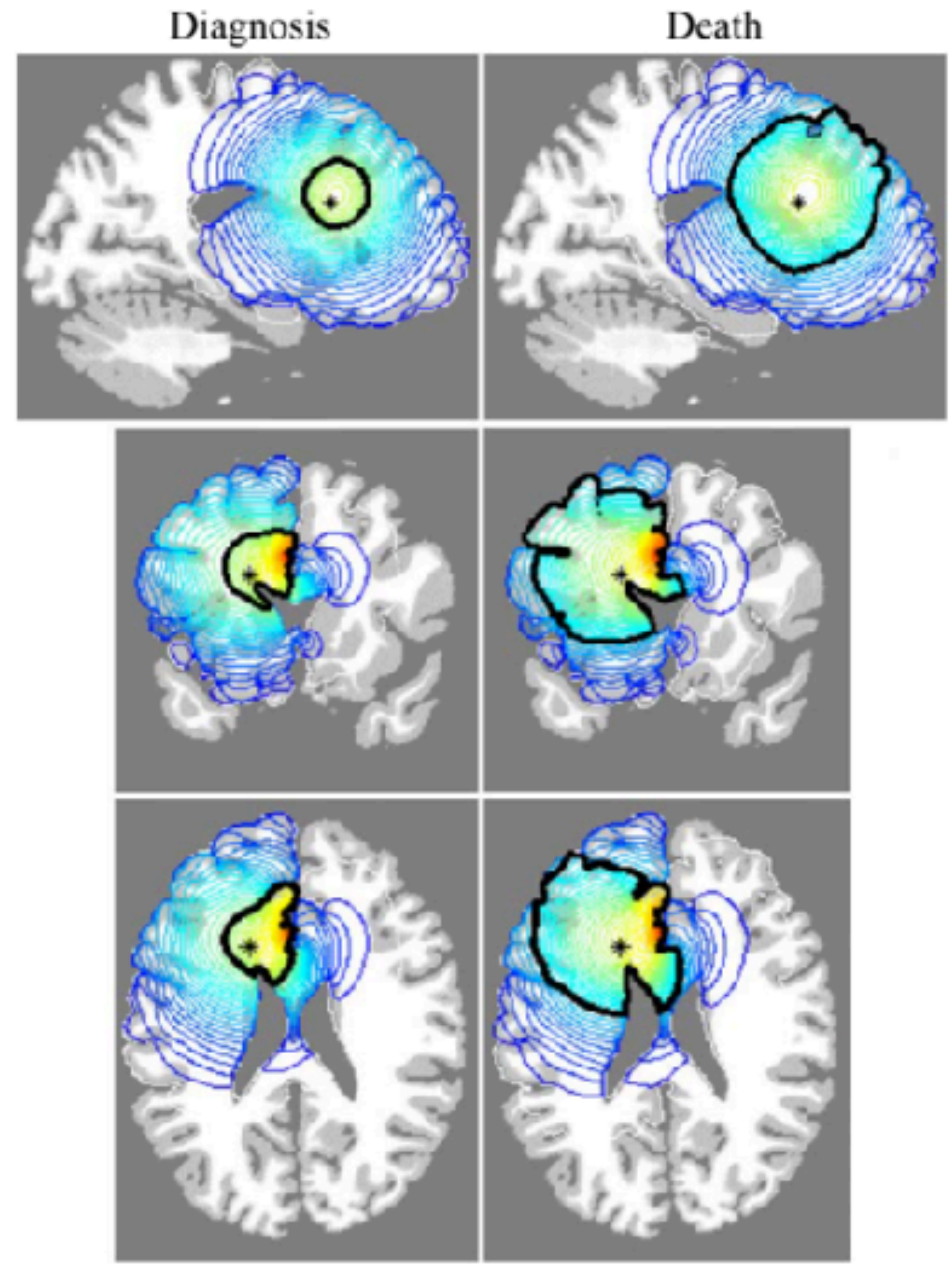


Rejniak & Anderson - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3057876/


a
b
54.8
c
d
e
f
= 0.25
g
400
300
500
500
400
h
i
j
k
l

Imaging data

- Exists at many scales — landscapes to cells
- Often requires some image processing to identify regions with key features for the agents to interact with
- We've seen another example of this in the model of the Ancestral Puebloan communities that we looked at previously



Swanson et al. 2003 Virtual and real brain tumors: using mathematical modeling to quantify glioma growth and invasion

Mapping data

- Often used for modeling commuting patterns, disease spread, social dynamics, etc.

- Modeling with mapping is similar to other ABM with space, just using the map to determine where features are

- Example: FRED synthetic population model

- https://fred.publichealth.pitt.edu/measles