Artificial Societies
(Social Science from the Bottom Up)

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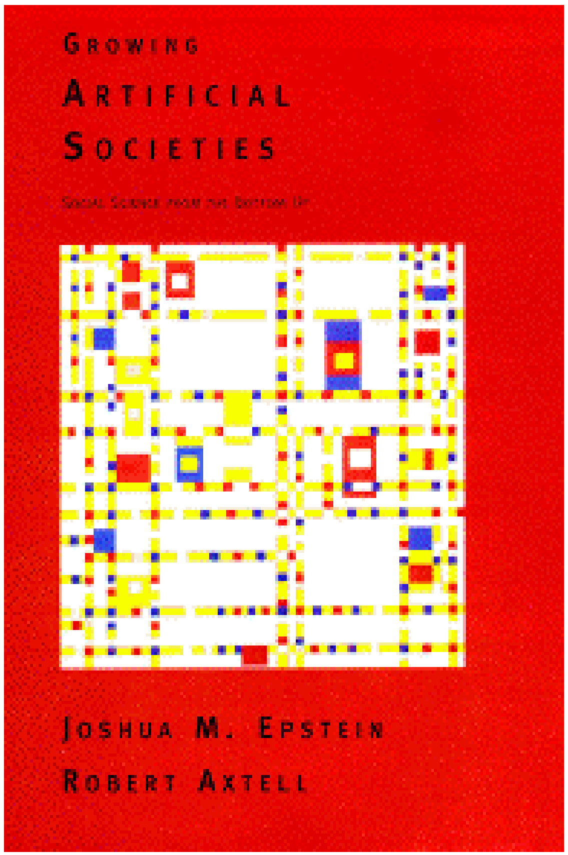
Overview

- Introduction
- The “Sugarscape” model
- Four case studies
- Demo
- Concluding remarks

Axtell & Epstein book



“Growing Artificial Societies: Social Science from the Bottom Up”

By Joshua M. Epstein and Robert Axtell

A Collaborative Effort of the Brookings Institution, the Santa Fe Institute and the World Resources Institute

Brookings Institution 1996

Axtell & Epstein book

- **Joshua M. Epstein** (MIT: political science)
  - Brookings senior fellow from 1987 to 2010 and Director of the Center on Social and Economic Dynamics
  - Now faculty at the Department of Emergency Medicine at Johns Hopkins University and member of the External Faculty of the Santa Fe Institute
- **Robert L. Axtell** (CMU: computing, social science, public policy)
  - Brookings senior fellow from 1992 to 2007
  - Professor at George Mason University, Krasnow Institute for Advanced Study, Departmental Chair of the Department of Computational Social Science and member of the External Faculty of the Santa Fe Institute
- Primary research interest: modeling of complex social, economic, and biological systems using computational agent based models

Introduction

- Social sciences are “hard” sciences [Herb Simon]
  - Social processes are complex and there is no natural methodologies for studying them
  - Difficult to test hypotheses concerning the relationship of individual behaviors to macroscopic regularities
  - No natural methodology for systematically studying highly heterogeneous populations
  - Pre-occupied with static equilibria; no natural methodology for studying non-equilibrium dynamics in social systems
- Controlled experimentation. How?

Key problem

- **Question of interest:**

  if individuals do X, then society does Y
- **How does the heterogeneous micro-world of individual behaviors generate the global macroscopic regularities of the society?**

"Classical" assumptions

- **Rational Actor Requirements:**
  - **Perfect information**
  - **Perfectly informed**
  - **Infinite computing capacity**
  - **Maximizes a fixed (non-evolving) exogenous utility function**
- **Do you know anyone like this????**
- **The assumption "Perfectly informed individual with infinite computing capacity who maximizes a fixed exogenous utility function" bears little relation to a human being**

Limitations of “classical” approaches

- Suppress real-world agent heterogeneity in model-building
  - As in macroeconomics, filter out all consequences of heterogeneity
- Game theory and general equilibrium theory are focused on static equilibriums
  - That is not realistic!

Limitations of “classical” approaches

- Ignored time dynamics
- No-natural methodology for studying non-equilibrium dynamics

Epstein and Axtell: Contribution

- New Methodology
- Help to overcome previous problems
- Approach departs from traditional disciplines in:
  - Way (combat, trade, cultural transmissions)
  - Combination

Focus of the new methodology

- Artificial Society Models
- Agent-based
- Computer modeling techniques to study
  - Trade, migration , group formation, combat, interaction with environment, transmission of “culture,” propagation of disease, dynamics
  - Human activity from an evolutionary perspective
- First attempts by Thomas Schelling (at that time, limited computational power), derived segregation of neighborhoods, even if people were “color blind”

Roots of the methodology

- Ashby 1956
- Wiener 1961
- Von Neumann 1966
- Rumelhart & McClelland 1986
- Toffoli & Margolus 1987
- Gasser & Huhns 1989
- Langton 1989, 1992, 1994
- Gutowitz 1991
- Holland 1992
- Koza 1992, 1994
- Wolfram 1994
- Brooks & Maes 1994
- Haefner & Crist 1994
- Crist & Haefner 1994

Like with all scientific developments, there is a long line of developments that has led to the current state of this research

Artificial Societies

- **Agent-based models**
- **Social Processes**
- ***Group Behaviors emerge from interaction of individuals operating in artificial environments under rules.***

Goal of Artificial Societies

- To discover fundamental local or micro-mechanisms that are sufficient to generate the macroscopic social structures and collective behaviors of interest
- Three basic ingredients
  - Agents
  - An environment or space
  - Rules
- Agent-based models of social processes are called “artificial societies”
- Artificial societies are “laboratories” where certain social structures can be “grown”
  - From the bottom (agents) up (macroscopic patterns)
  - e.g., certain stable wealth distributions

Goal of Artificial Societies

"… In the beginning, a small population of agents is randomly scattered about a landscape. Purposeful individual behavior leads to most capable or lucky agents to the most fertile zones of the landscape; these migrations produce spatially segregated agent pools. Though less fortunate agents die on the wayside, for the survivors life is good: food is plentiful, most live to ripe old ages, populations expand through sexual reproduction, and the transmission of cultural attributes eventually produces spatially distinct "tribes." But their splendid isolation proves unsustainable: populations grow beyond what local resources can support, forcing tribes to expand into previously uninhabited areas. There the tribes collide and interact perpetually, with penetrations, combat, and cultural assimilation producing complex social histories, with violent phases, peaceful epochs, and so on."

Agent-based modeling techniques

… are applied to the study of human social phenomena

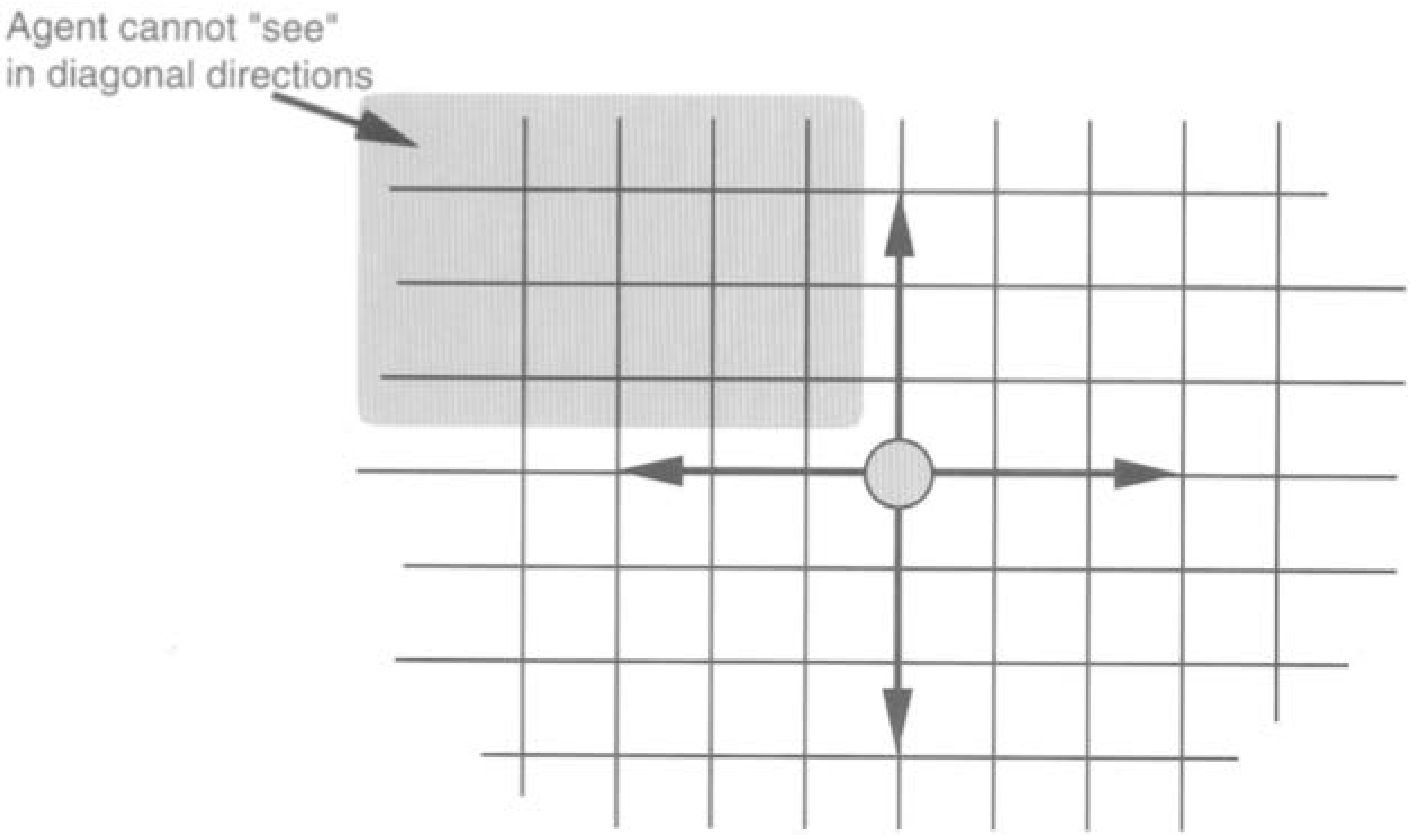
- Trade
- Migration
- Group Formation
- Combat
- Interaction with the environment
- Transmission of culture
- Propagation of disease
- Population dynamics

Agents

- Agents are the “people” of artificial societies
- Each agent has internal states
  - Some are fixed, e.g., sex, metabolic rate, vision
  - Some are changeable with the interaction with other agents of the environment, e.g., economic preferences, wealth, cultural identity, and health
- Each agent has behavioral rules (fixed or flexible)
  - e.g., mating rule, combat rule, or trade rule
- Agents move around and interact with each other, impacting the changeable components (of their states and of the environment)

Agent vision

Figure II-3. Agent Vision



Example of an agent’s rule of behavior

- Agent movement rule M:
  - Look out as far as vision permits in the four principal lattice directions and identify the unoccupied site(s) having the most sugar;
  - If the greatest sugar value appears on multiple sites, then select the nearest one;
  - Move to this site;
  - Collect all the sugar at this new position.

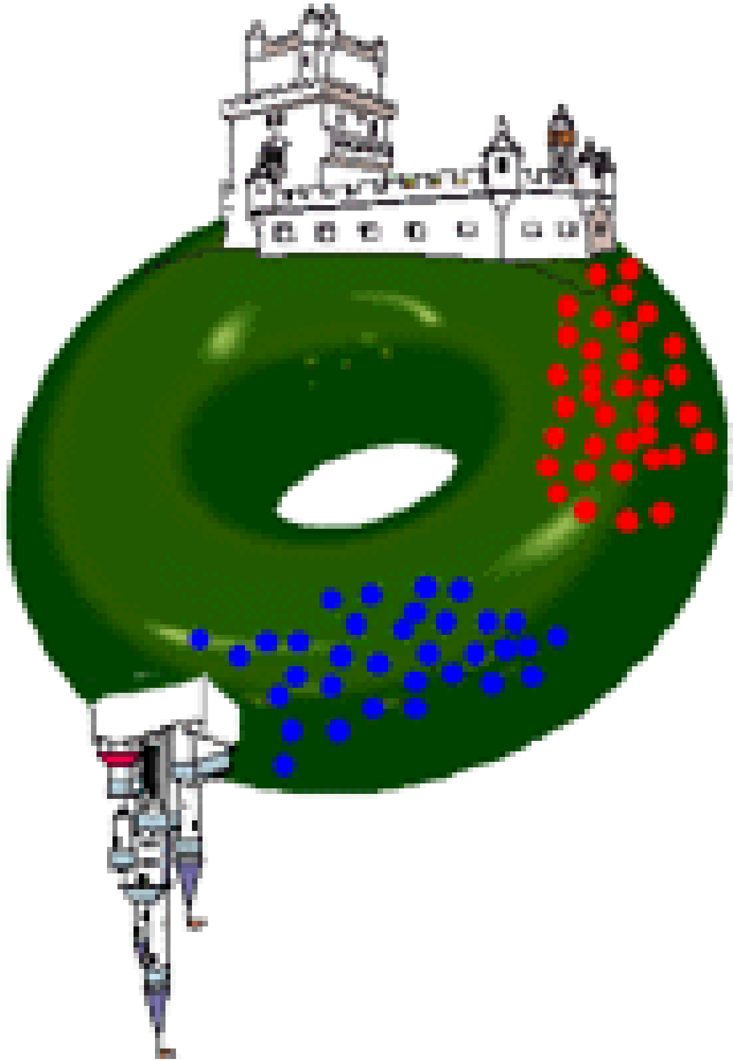
Environment

- Where life in an artificial society unfolds
- Could be landscape
  - A topography of renewable resource that agents eat and metabolizes
  - A landscape is naturally modeled as a lattice of resource-bearing sites
- Support strata for the agents to eat
- Could be a more abstract structure
  - e.g., a communication network with changeable connection geometry
- "Is a medium separate from the agents, on which the agents operate and with which they interact?"

Object-oriented implementation

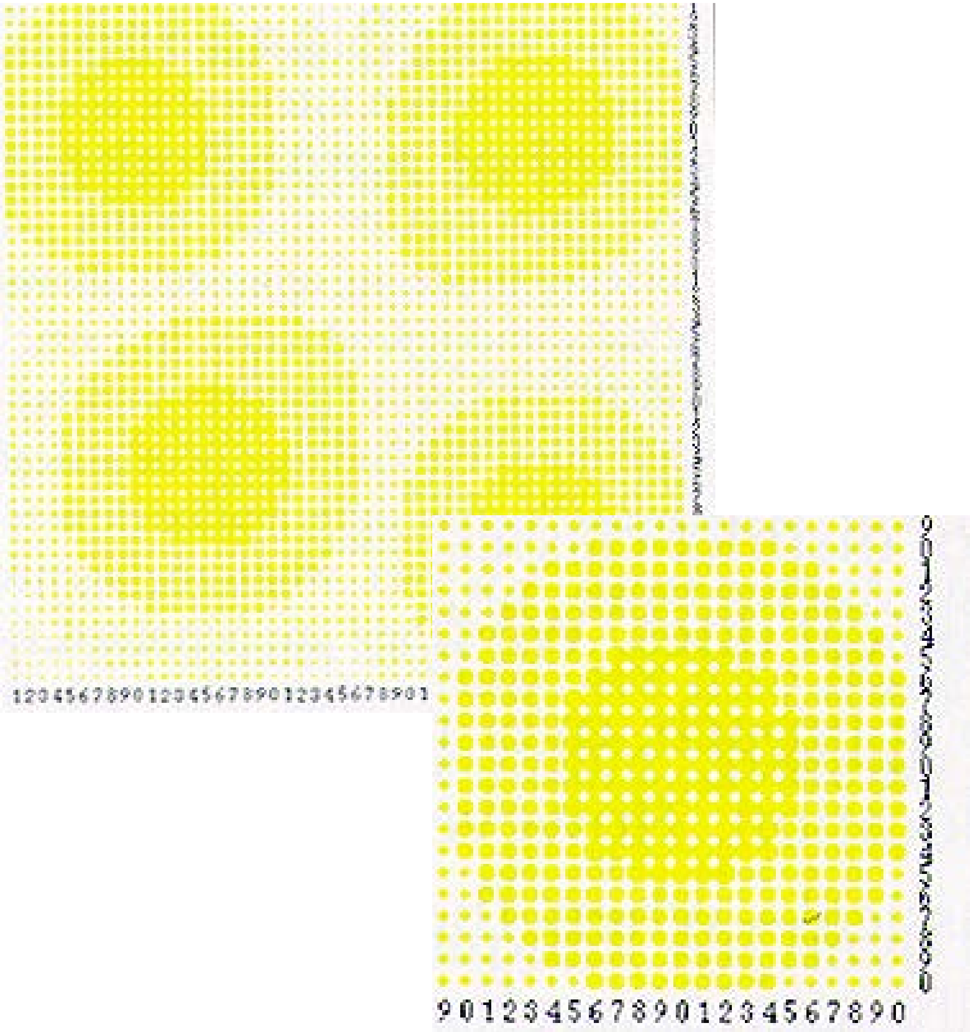
- Object-oriented programming is natural for agent-based modeling
- Can both represent data (internal states, such as sex, age, health) and procedures/methods (hold rules of behavior, such as eating and trading)

Environment: Sugarscape



Environment: Sugarscape

- The “World” is a grid
- Every site has a sugar capacity
- Sugar replenishes according to some rule G (e.g., at some constant rate)
- Agents are initialized randomly



Rules of behavior

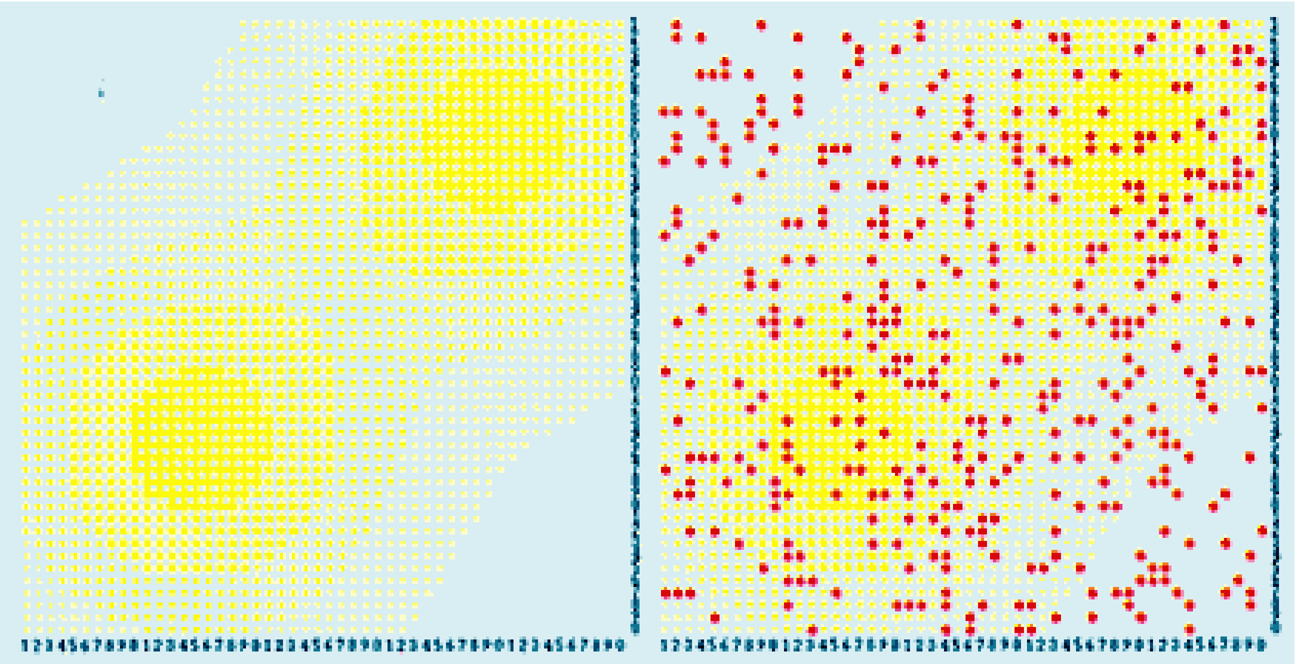
There are rules of behavior for the agents and for the sites of the environment.

- Agent-agent interactions
  - » e.g., mating, combat, trade
- Environment-environment rule
  - » e.g., grow back to full capacity immediately, grow back incrementally over time, grow back at a rate determined by surrounding cells
- Agent-environment rule
  - » e.g., look around as far as you can, find the site richest in food, go there, and eat the food

Technology underlying the model

- OOP languages are particularly natural ones for agent-based modeling
- Both agents and environmental sites are naturally implemented as objects
- The agent's data fields represent its internal states
- The agent's procedures are the agent's rules of behavior, e.g., eating

The “Sugarscape”

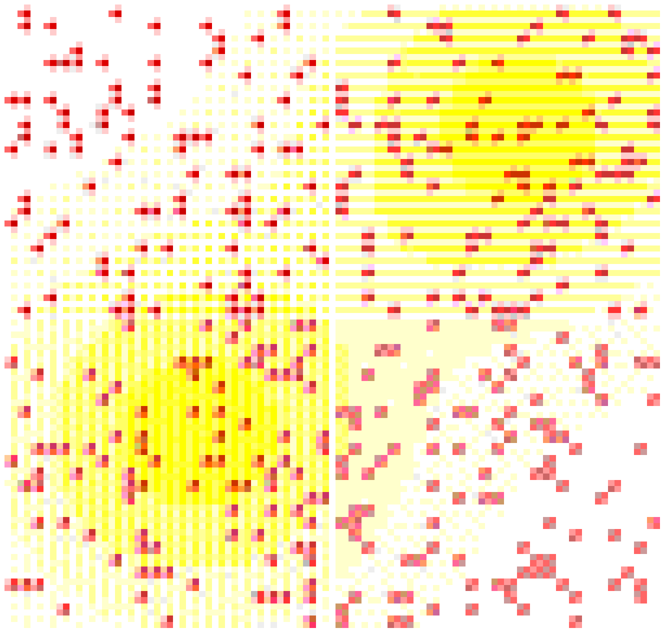


- A 2D grid with 2,500 locations arranged on a 50x50 lattice
- At every point on the grid, there is both a sugar level and a sugar capacity (initially at its capacity)
- Sugar score is highest at the peaks in the northeast and southwest quadrants of the grid

The "Sugarscape" model

The Emergence of Social Structures

The defining feature of an artificial society is that fundamental social structures and group behaviors emerge from the interaction of individual agents operating on artificial environments under rules that place only bounded demands on each agent's information and computational capacity.



Collective structures are grown from bottom up!

Life and death on the Sugarscape

As the system evolves, a wide range of phenomena emerge

- **Carrying capacity**
- **Migration**
- **Skewed wealth distribution**

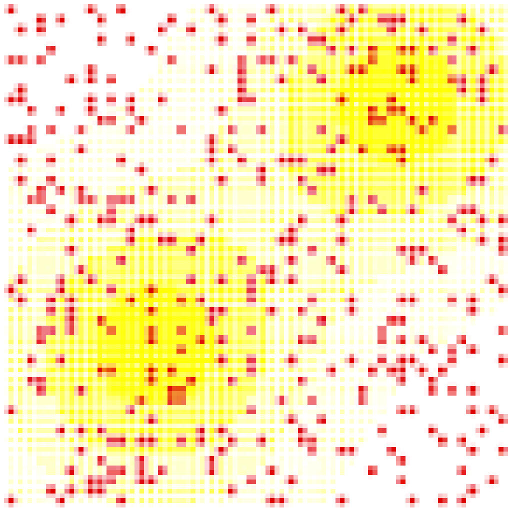
The Sugarscape acts as a *CompuTerrarium*

Simulation scenarios

- Simple “find food & eat it”
- Sexual reproduction
- Combat (take resources by force)
- Trading behavior
- Rise of credit networks
- Social networks
- Disease

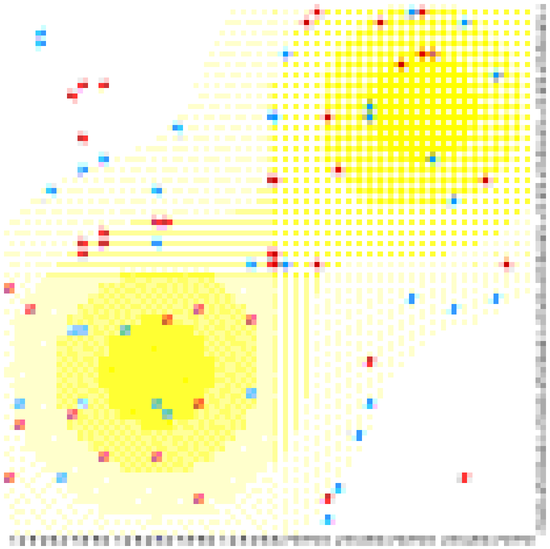
Simple “find food & eat it”

- Agents (in red) harvest sugar (yellow) from a landscape
- Each period each agent searches its neighborhood for the site richest in sugar, moves there and harvests the sugar
- Sugar grows back at unit rate
- Agents die if they are unable to find enough food to satisfy their metabolic demands



Sexual reproduction

- Agents are randomly assigned to belong to either the "red" culture or the "blue" culture
- Agents engage in sexual reproduction and cultural exchange
- Assimilation is observed
- Overpopulation occurs forcing some agents to move to less "fertile" regions



Combat (take resources by force)

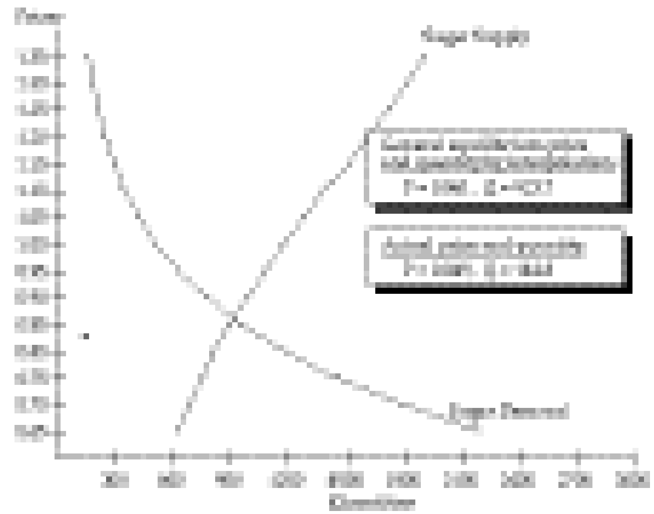
- Goal: rob sugar from agents from other tribes
- Rules:
  - able to win
  - avoid revenge
- Observation: localized war

Trading behavior

- New attributes:
  - any spicy food around?
  - Trade on negotiated price
- Rule: eat healthy
- Observation:
  - trade in a decentralized fashion: local price
  - increased the carrying capacity of the environment
  - increased social inequality: horizontal inequality

Trading behavior

- A second consumable, spice, is introduced
- Agents differ in there utility for sugar and spice facilitating trading
- Trading takes place locally, between two agents
- There are no clearing houses or brokerages
- Aggregate characteristics of supply and demand can be plotted dynamically



Rise of credit networks

- **New attributes:**
  - loan & due date
  - negotiated price
- **Rule:**
  - raise children
- **Observation:**
  - lender
  - borrower

Carrying capacity (ecology and environmental studies)

Figure II-4. Time Series of Population under Rules ({G_1}, {M}) from a Random Initial Distribution of Agents; Asymptotic Approach to the Environmental Carrying Capacity of 224

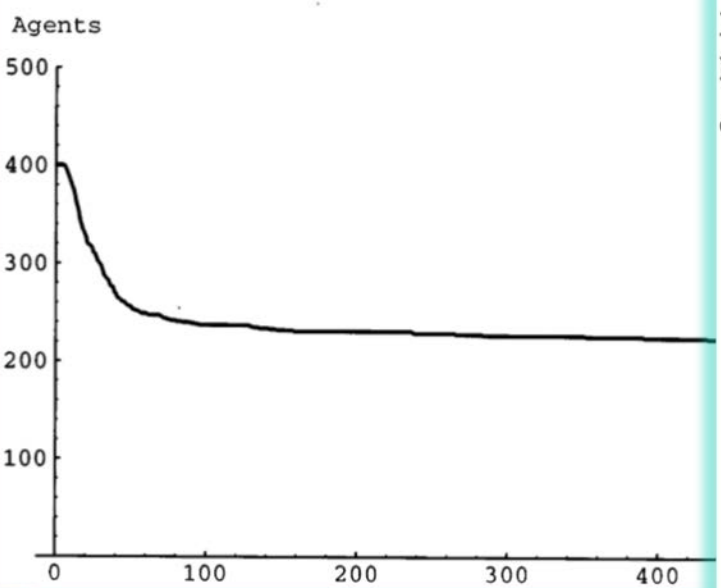
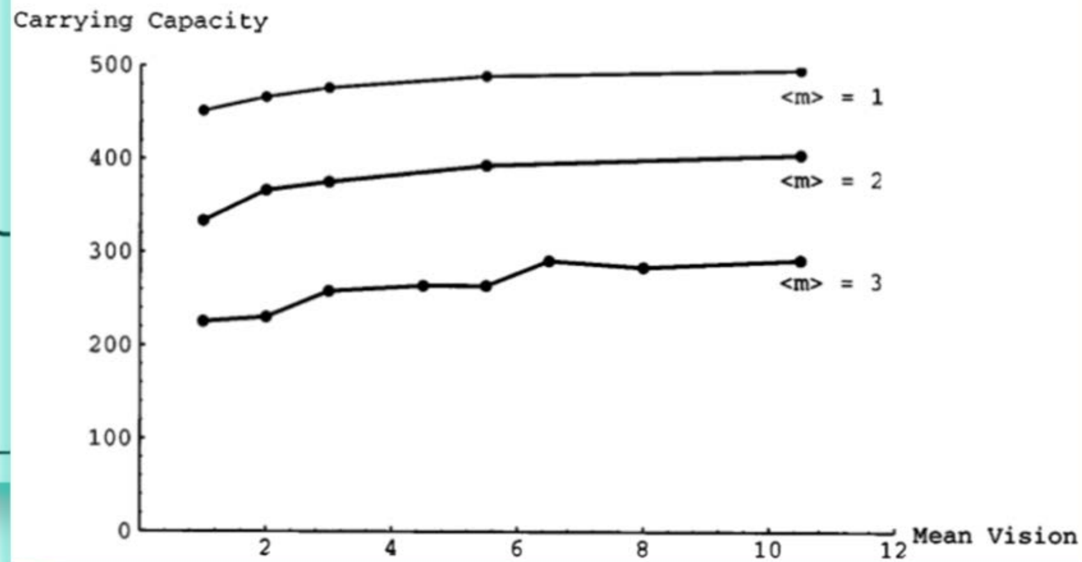


Figure II-5. Carrying Capacities as a Function of Mean Agent Vision, Parameterized by Metabolism, under Rules ({G_1}, {M}) from a Random Initial Distribution of Agents



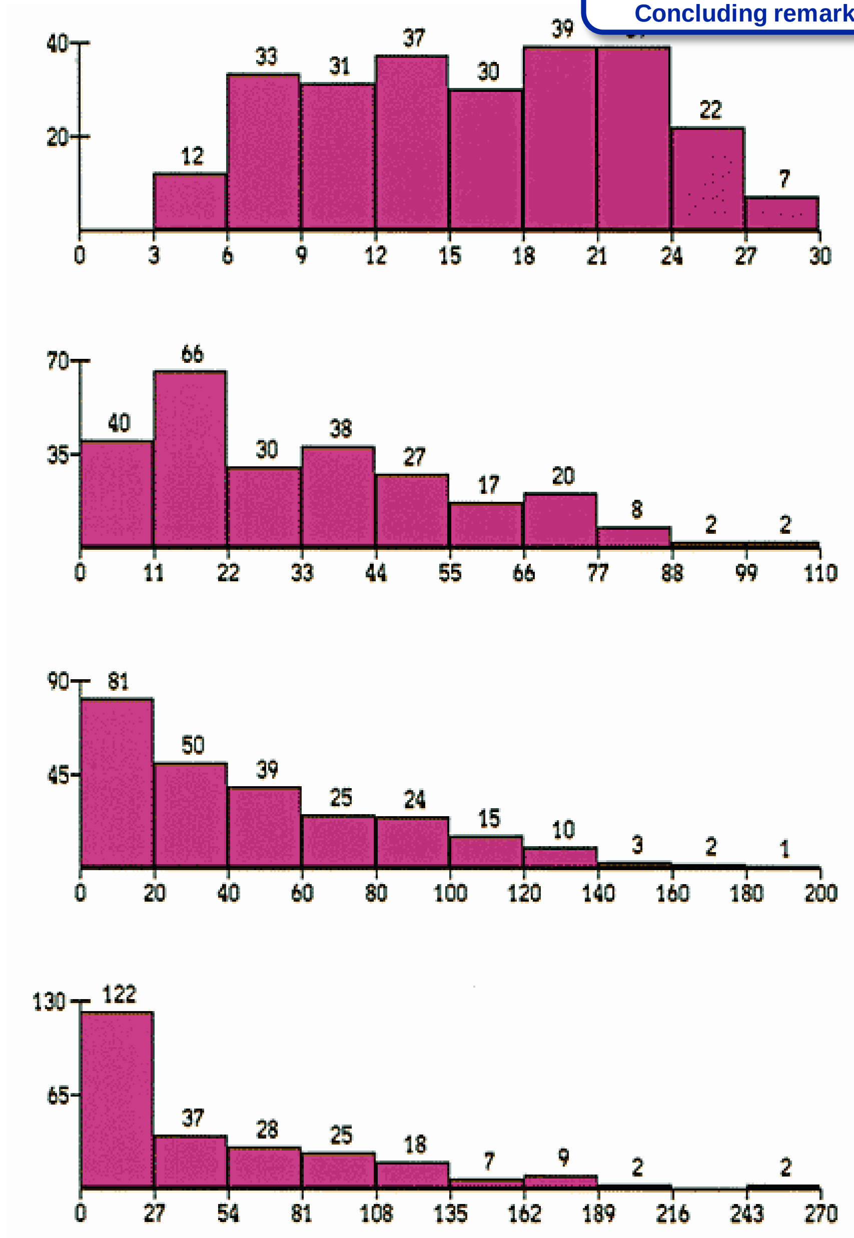
- **Carrying Capacity**
  - **This simulation illustrates “carrying capacity”: A given environment will not support an indefinite population of agents**
  - **400 agents at the beginning**
  - **A carrying capacity of approximately 224 is eventually reached**

Natural Selection

- A primitive form of Sugarscape also illustrates a central idea of evolutionary theory “selection”
- Metabolism and vision are randomly distributed initially
- By the time the carrying capacity is attained, the population is skewed in favor of agents with low metabolism and high vision
- e.g., the initial mean vision and metabolism were 3.5 and 2.5, respectively; after 500 time periods, selection had increased mean vision to 4.1 and reduced mean metabolism to 1.8

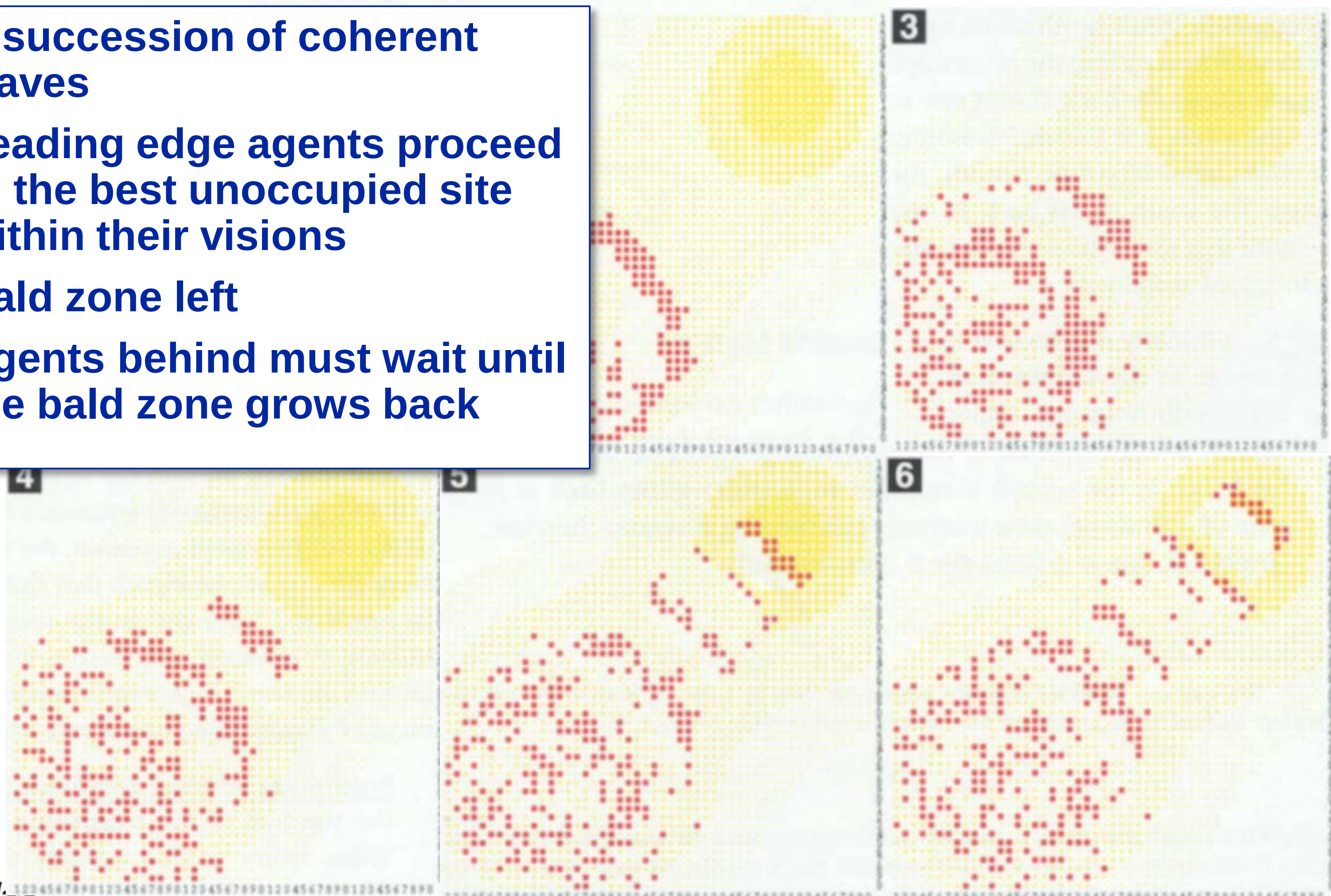
Wealth Distribution

- **Modification of previous runs:**
  - **Maximum achievable age**
  - **A constant population**
- **While initially quite symmetrical, the distribution ends up highly skewed**



Migration

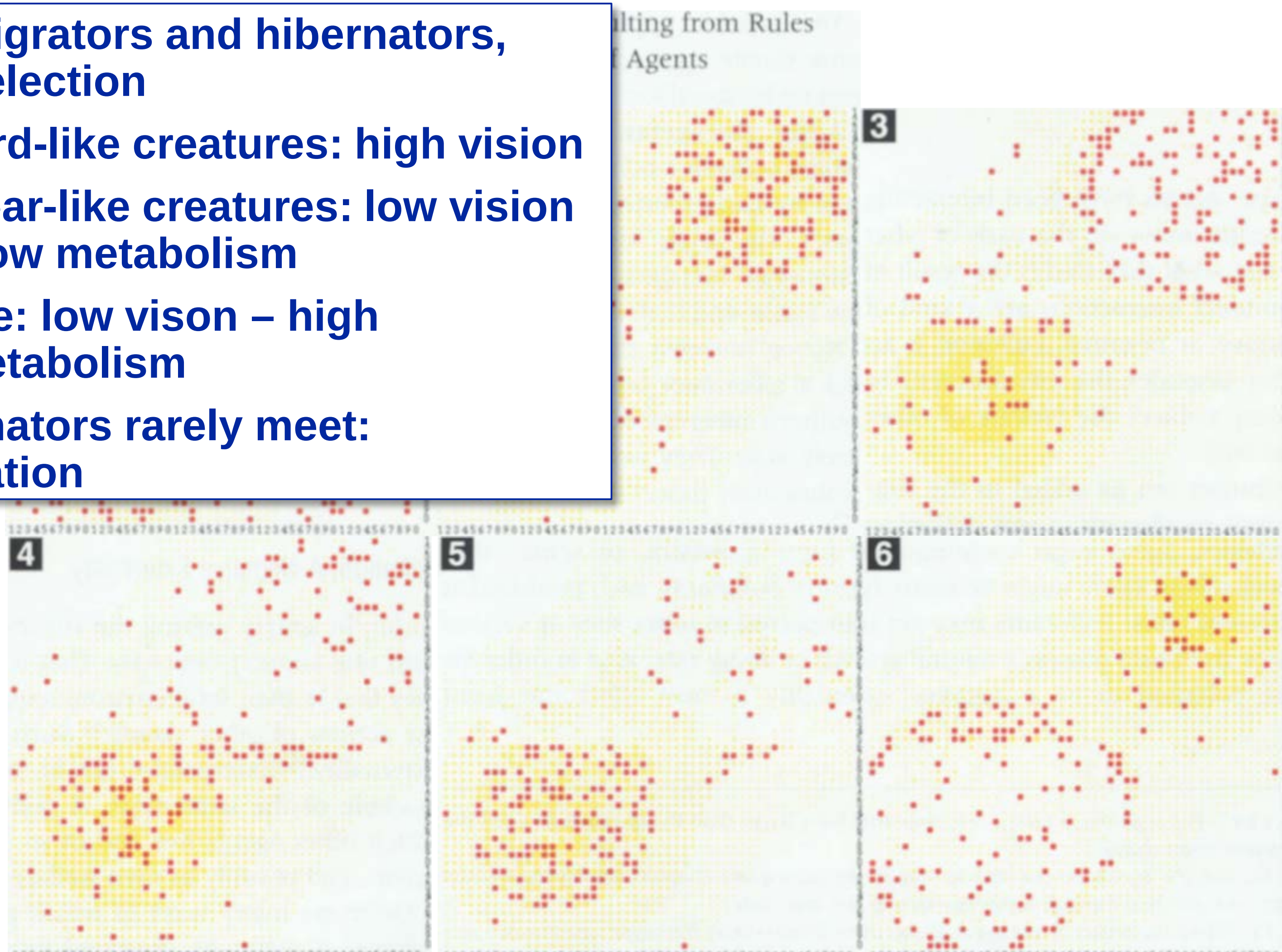
Animation II-6. Emergent Diagonal Waves of Migrators under Rules ({G_1}, {**M**}) from an Initial Distribution of Agents in a Block



- **A succession of coherent waves**
- **Leading edge agents proceed to the best unoccupied site within their visions**
- **Bald zone left**
- **Agents behind must wait until the bald zone grows back**

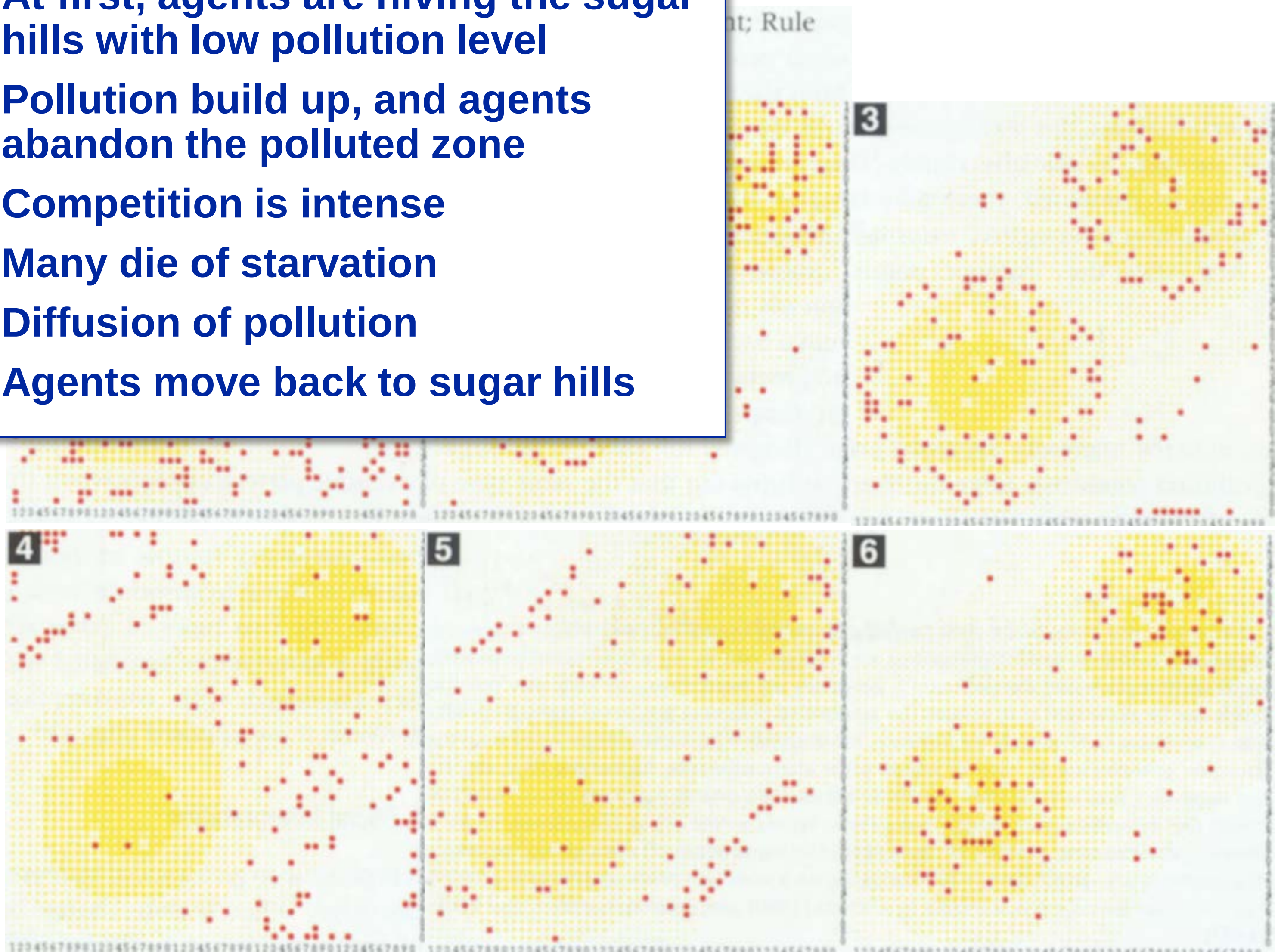
Seasonal Migration

- Get migrators and hibernators, and selection
  - –Bird-like creatures: high vision
  - –Bear-like creatures: low vision - low metabolism
  - –Die: low vison – high metabolism
- Hibernators rarely meet: speciation



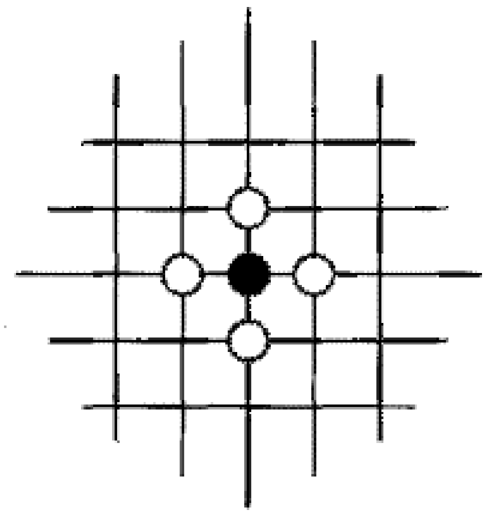
Migration in a polluted environment

- At first, agents are hiving the sugar hills with low pollution level
- Pollution build up, and agents abandon the polluted zone
- Competition is intense
- Many die of starvation
- Diffusion of pollution
- Agents move back to sugar hills

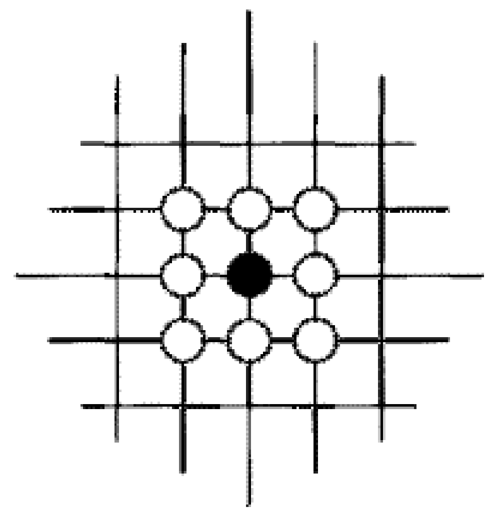


Social networks

- **To keep track of each agent’s neighbors during the whole simulation**
- **Two ways to define a “neighbor”**



von Neumann

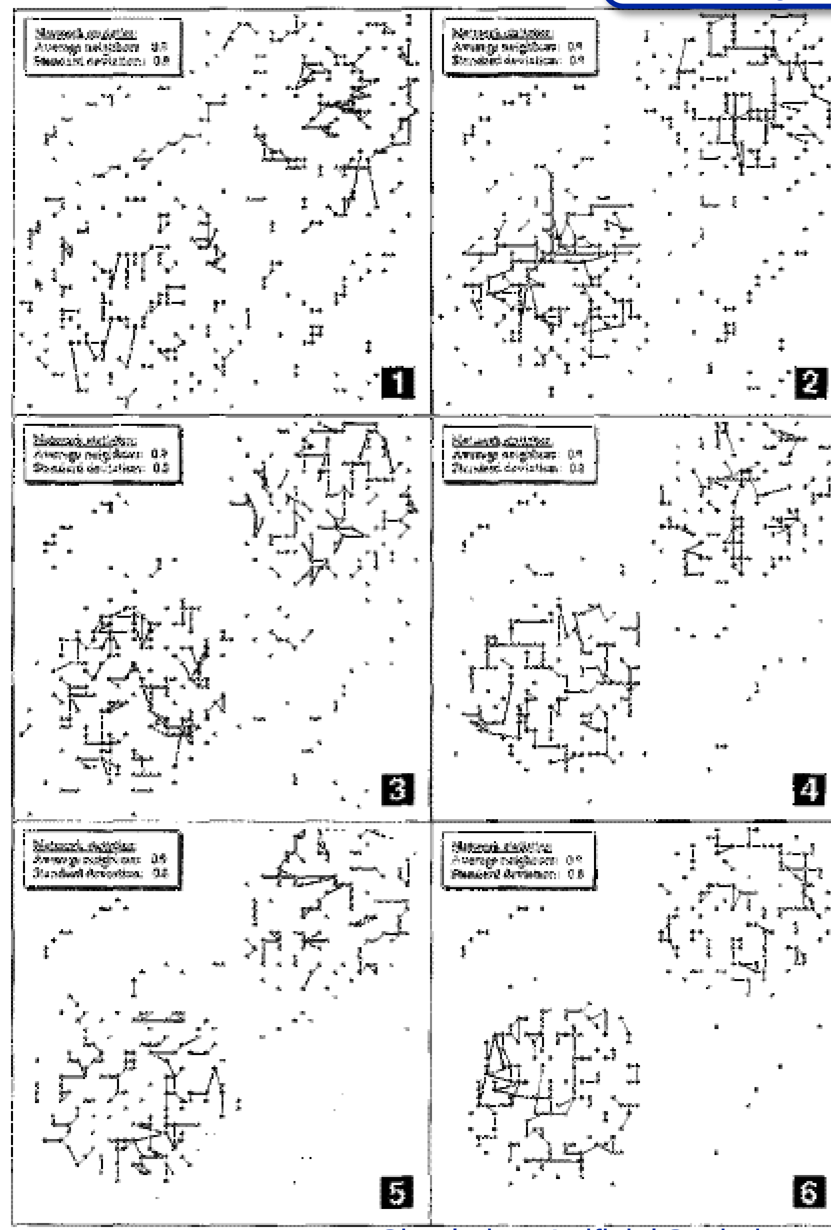


Moore

Social networks

- Agent = autonomous processing node in a computer
- Individual (local) optimality --?--> overall social (global) optimality
  - (massively parallel computer, its interaction is evolving through time)

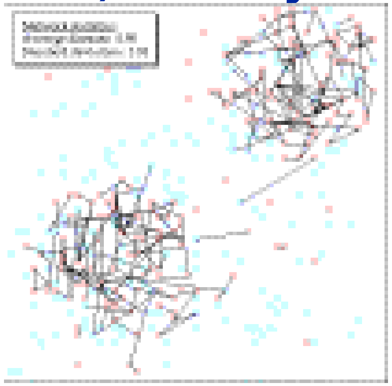
Social networks



- Clearly, a rich variety arises
- It implies the chance that a message could make its way across the sugarsacpe
  - If we whisper in the ear of a southwestern agent, will a northeastern agent hear it?

Disease

- Disease is introduced into the model
- Transmission can be monitored
- Agents carrying the disease are shown in red and healthy agents are shown in blue
- Relationships between the an agent ‘A’ who transmits a disease and an agent ‘B’ who contracts the disease from agent A can be visualized by drawing lines between both agents
- Rule: more sugar consumption
  - Disease pattern affected by social improvement, military conquest, and migration



Links

- http://sugarscape.sourceforge.net/
- http://www.brookings.edu/press/Books/1996/artifsoc.aspx
- http://mitpress.mit.edu/catalog/item/default.asp?tid=5847&ttype=2

Conclusion

- These simulations make clear that a wide range of collective structures and patterns of behavior can emerge from the spatio-temporal interaction of agents operating, individually, under simple local rules
- These simulations are surprising; the surprise comes from the emergence of familiar macrostructures from the bottom up—from simple local rules that appear quite remote from the social phenomena they generate
- Artificial social systems such as Sugarscape provide a convenient way to study social science