Agent-Based Modeling

History and Applications

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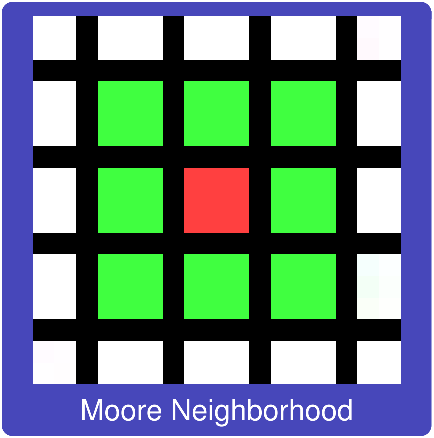
Outline

Agents

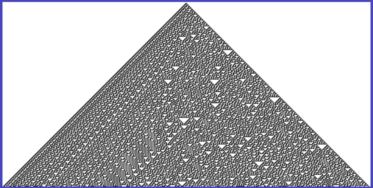
"An agent is an entity whose state is viewed as consisting of mental components such as beliefs, capabilities, choices, and commitments. . . . [A]genthood is in the mind of the programmer: What makes any hardware or software component an agent is precisely the fact that one has chosen to analyze and control it in these mental terms."

Early Computing Research

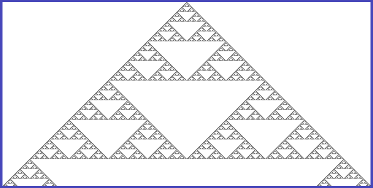
Definitions



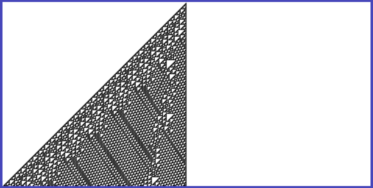
Wolfram’s One-Dimensional Automata



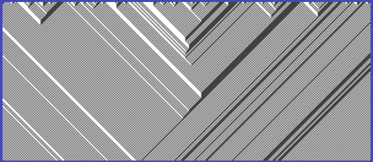
Rule 30
Cryptographically Random



Rule 90
Sierpiński Automaton



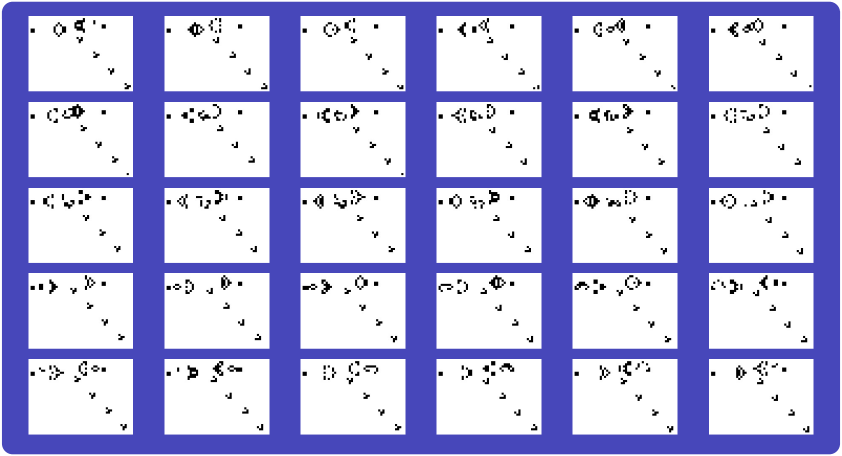
Rule 110
Turing-Complete



Rule 184
Basic Traffic Simulation

Wolfram, S. (2002). *A New Kind of Science*.

Conway's Game of Life

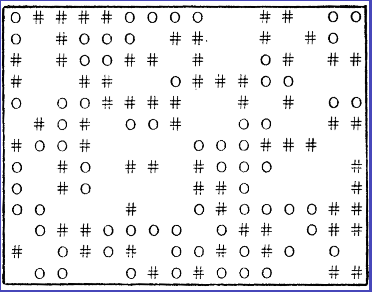


Schelling's Model of Ethnic Segregation

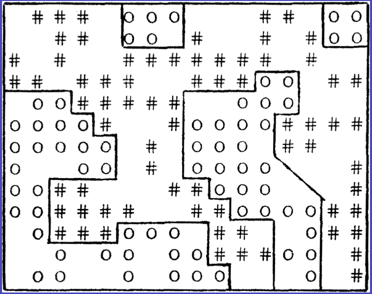
Rules of the Simulation

- Agents are divided into two groups: A and B
- A space on the board can be unoccupied, or occupied by an agent from either group
- An agent's neighborhood uses Moore (8-way) adjacency
- An agent is content with its neighborhood if at least n% of its neighbors are in the same group
- Resolve the simulation as follows:
  - Choose a random agent
  - If it is not content, move it to the closest available space in which it would be content
  - Repeat until all agents are content

Schelling’s Model of Ethnic Segregation



Initial Population



Final Population

The SimCity Analogy

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Why Agent-Based Modeling?

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- Randomness

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- Randomness
- Heterogeneity
- Interactions

Main Elements of an Agent-Based Model

- Agents
- Environment
- Time-Keeping
- Interactions

Agents

- Heterogeneous
- State-Based
- Contain Information
- Reproduction and Death
- Necessities of Life

Environment

- Spatial Relationships
- Travel Restrictions
- Interactions with Agents

Time-Keeping

- Synchronous (“Time-Driven”)
- Asynchronous (“Event-Driven”)

Time-Keeping: Synchronous Time

Algorithm 1 Synchronous update scheme

Set initial time.
Set initial conditions for all agents and the environment.
loop
    for all agents in the model **do**
        Invoke update rule.
    end for
    Increment time to next time step.
end loop

Time-Keeping: Asynchronous Time

Algorithm 2 Asynchronous update scheme

Set initial time.
Set initial conditions for all agents and the environment.
loop
    Update time to that of the next event.
    Determine which agent(s) will be updated next and which update rule will be applied.
    Apply the selected rule to the selected agent(s).
    Update the schedule.
end loop

Artificial Intelligence

"If you stack bricks one atop the other, eventually you'll reach the moon."

Artificial Intelligence

- Knowledge and belief
- Inference
- Social models
- Knowledge representation
- Goals
- Planning
- Language
- Emotions

Production Systems

- Rules
- Working memory
- Rules interpreter

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- Rules
- Working memory
- Rules interpreter
- In other words, a lot of If/Else clauses

Example: Simple Model of Malaria

Rules of the Simulation

- Two types of agents: humans and mosquitos
- Agents live in a rectangular environment of size $L \times L$
- Agents can be either infected or not
- If a mosquito is infected, it infects all humans in radius b
- If a mosquito is not infected, and there is an infected human in radius b, the mosquito becomes infected
- Once infected, humans remain infected for R_h time steps, while mosquitos remain infected for R_m time steps
- Each time step, each agent moves at most s_h or s_m (humans and mosquitos, respectively) steps in a random direction

Other Techniques from Machine Learning

- Genetic Algorithms
- Neural Networks
- Reinforcement Learning

More Sophisticated Interactions

- Simplistic interaction models have given agent-based modeling a bad reputation

More Sophisticated Interactions

- Behavioral Economics
- Behavioral Game Theory
- Psychology
- Philosophy of Mind

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- Psychology
- Philosophy of Mind
- Sociology

Why Economics?

- Large-scale features emergent from microfoudnations
- Driven primarily by interactions between market participants
- Extremely socially relevant
- Feasible to model

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- Large-scale features emergent from microfoudnations
- Driven primarily by interactions between market participants
- Extremely socially relevant
- Feasible to model
- Video games, however, are not (currently) a real solution

LeBaron's Model of Stock Price Volatility

Rules of the Simulation

- Two types of securities:
  - Risk-free bonds, in infinite supply, yielding 1% annually (compounded monthly)
  - Risky stock, in limited supply, with a semi-random divided having 2% annualized growth with 6% standard deviation
- Trading strategies are devised externally, and all agents can select from the strategy pool
- Strategies are created using a feedforward neural network
- Each agent has a "memory length," or, the length of time over which they consider price history when evaluating strategies against historical data

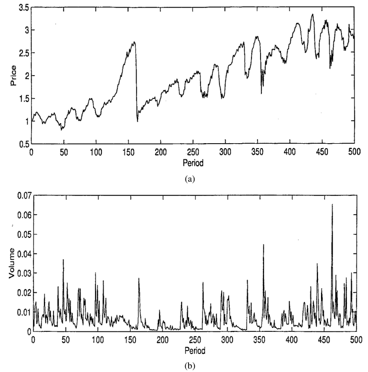
LeBaron's Model of Stock Price Volatility

Rules of the Simulation (continued)

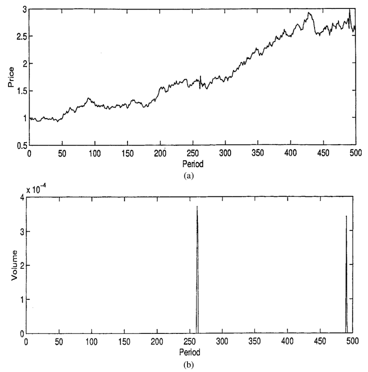
- Periodically, the strategies are evolved using a genetic algorithm, first by removing all strategies that were not used recently, then by randomly applying one of the three following criteria:
  - Change one weight (selected at random) in the strategy
  - Replace one weight (selected at random) in the strategy with a new random value
  - Combine two randomly-selected strategies into one new strategy
- Shares of the risky asset are traded by numerically computing its expected equilibrium price
- Differences in memory length drive differences in strategy choice

LeBaron, B. (2001). Empirical regularities from interacting long and short horizon investors in an agent-based stock market.

LeBaron's Model of Stock Price Volatility



All-Memory



Long-Memory

Seppecher: Wage Flexibility and Aggregate Demand

Rules of the Simulation

- Three agent types: households, firms, and one representative commercial bank
- Real and monetary goods independent
- Rules of the bank:
  - Accepts deposits from households
  - Issues loans to firms
  - If a firm defaults, it is issued a *doubtful* loan to cover its previous loans
  - If a firm defaults on a doubtful loan, it goes into bankruptcy and is removed from the simulation
  - Defaulted loans are absorbed by the bank's capital
  - If the bank cannot cover a default, it goes into bankruptcy and the simulation ends

Seppecher: Wage Flexibility and Aggregate Demand

Rules of the Simulation (continued)

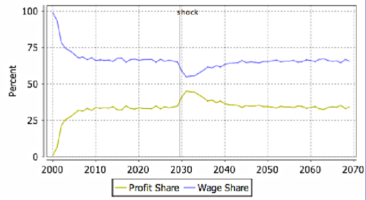
- Rules of firms:
  - Sets their quarterly production goals based on stocks left from last quarter
  - Uses production goals to set an employment level, hiring or firing as needed
  - If hiring, adjusts wages it posts to the labor market based on its previous ability to fill posted positions
  - Takes credit to cover payroll, if needed
  - Adjusts goods prices based on post-production inventories
  - Pays part of its profits as dividends

Seppecher: Wage Flexibility and Aggregate Demand

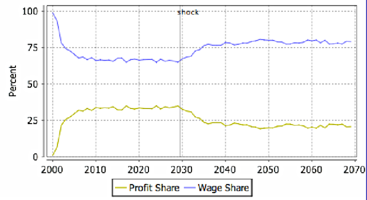
Rules of the Simulation (continued)

- Rules of households:
  - Has a reservation wage it would like to be paid
  - If unemployed, looks at a random set of job postings, and if the highest posting is above its reservation wage, it takes the job
  - If unemployed for at least n months, cuts the reservation wage
  - After being paid (if employed), saves some of its money in the bank, and spends the rest on the goods market
  - Households see a limited number of goods market postings, and buy the best deals

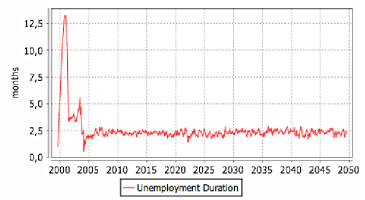
Seppecher: Wage Flexibility and Aggregate Demand

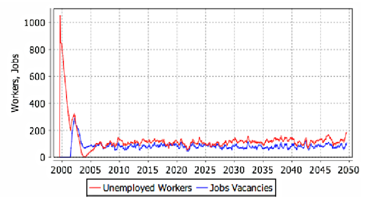


(a) Productivity shock



(b) Negative expenditure shock





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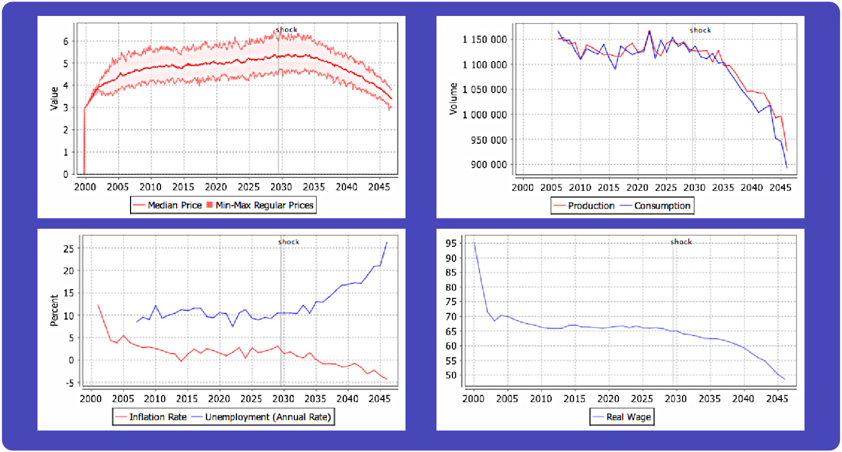

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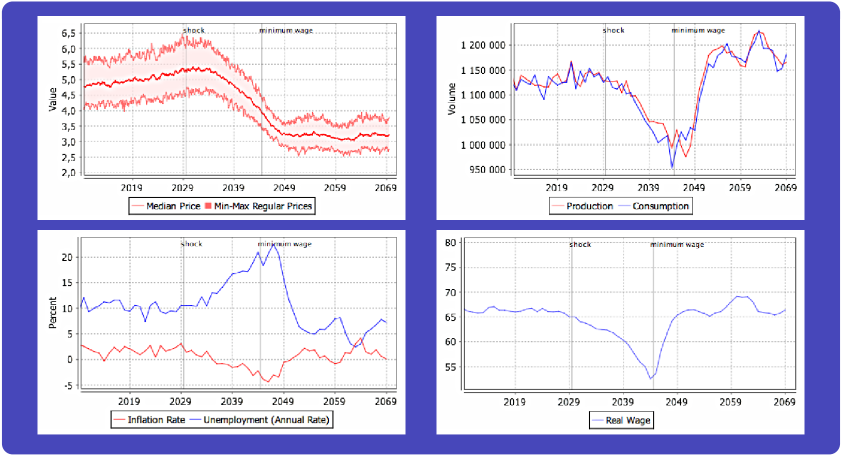

Conclusion

- Agent-based modeling has produced some promising results, with clear applications to the social sciences
- In particular, it is advantageous when a system contains randomness, heterogeneity, and complex interactions between agents
- A more comprehensive understanding of human decision-making is likely needed to move the technique forward

Questions