

### Agent-Based Modeling History and Applications

### Sean Williams

Department of Computer Science University of California, Davis

Computer, Computational, & Statistical Sciences Division Los Alamos National Laboratory

Quantifying Social Fields, 2012



### Outline

### History

Cellular Automata Cellular Automaton Applications Agent-Based Models

### Implementation

Four Concerns Interactions

### Results

Agent-Based Computational Economics

Conclusion

Williams, Agent-Based Modeling

∃ ► < ∃ ►</p>

< < >> < <</>

Cellular Automata

### 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."

Cellular Automata

### Early Computing Research





Cellular Automata

### Definitions

von Neumann Neighborhood	Moore Neighborhood

Gilbert, N. and Troitzsch, K. (1999). Simulation for the Social Scientist.

Williams, Agent-Based Modeling

æ

イロン イロン イヨン イヨン

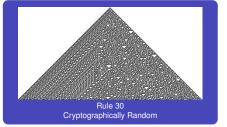


Implementation

Results 0 000 000000

**Cellular Automaton Applications** 

### Wolfram's One-Dimensional Automata





Sierpiński Automaton

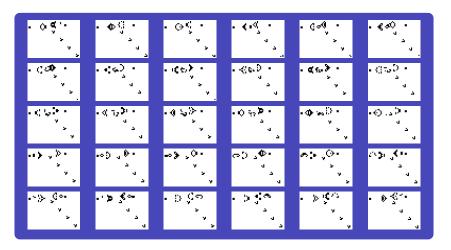


Wolfram, S. (2002). A New Kind of Science.

#### Williams, Agent-Based Modeling

**Cellular Automaton Applications** 

### Conway's Game of Life



< E

< < >> < <</>

# 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

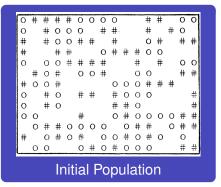


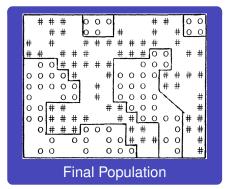
Implementation

Results 0 000 000000

Cellular Automaton Applications

## Schelling's Model of Ethnic Segregation





< < >> < <</>

Schelling, T. C. (1971). Dynamic models of segregation. J. Math. Sociol.

### The SimCity Analogy



æ

◆□ > ◆□ > ◆豆 > ◆豆 >

Implementation

Results 0 000 000000

Agent-Based Models

### The SimCity Analogy



E

◆□ > ◆□ > ◆豆 > ◆豆 >

Implementation

Results 0 000 000000

Agent-Based Models

## Why Agent-Based Modeling?

Barnes, D. and Chu, D. (2010). Introduction to Modeling for Biosciences.

Williams, Agent-Based Modeling

E

◆□ > ◆□ > ◆豆 > ◆豆 >

# Why Agent-Based Modeling?

Randomness

E

# Why Agent-Based Modeling?

- Randomness
- Heterogeneity

# Why Agent-Based Modeling?

- Randomness
- Heterogeneity
- Interactions

## Main Elements of an Agent-Based Model

- Agents
- Environment
- Time-Keeping
- Interactions



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



- Spatial Relationships
- Travel Restrictions
- Interactions with Agents



- 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

・ 同 ト ・ ヨ ト ・ ヨ

## **Artificial Intelligence**

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

イロト イポト イヨト イヨト

## Artificial Intelligence

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

< E

< < >> < <</>

### **Production Systems**

- Rules
- Working memory
- Rules interpreter

### **Production Systems**

- 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<sub>h</sub> time steps, while mosquitos remain infected for R<sub>m</sub> time steps
- Each time step, each agent moves at most s<sub>h</sub> or s<sub>m</sub> (humans and mosquitos, respectively) steps in a random direction

∃ ► < ∃ ►</p>

< A > <

## 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

## More Sophisticated Interactions

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



Agent-Based Computational Economics

# Why Economics?

610 0		Browse Auctions					
None .			Unite Iseas				
thansteel		AL 9	Display an Dian				
Repet			Min IGH Left				
	There is a second secon		80 203 483		1103 0 10	19 31 9	in.
Angele -	12 Demosred 1		40 200 464		150.61	12112	-
Constrain	20 Thinger			Overere.			140
Conversion	1 There is		40 100 460		1000		100
Concernance Concernance	There are a		40 100 400	Hannister		00.00	-
OVER THEN CONFI	156 Hereford		80 200 121	Mann	1112	2 92	985
hourthe	I Tannerei B		80 488	Beneralisation.		20.510	100%
noest ne Delver	I Thanset		60 461	Collabola		0000	1015
	I Tanneei B		60 488	Gelonebula	100	1211	
	I Thanset					00.00	an
	I Tamerel B				10.5	32 63 <b>2</b> 1	ions.
	I S [Tassard B			Cristelula	1000	00.00	iain
	I C ITANAGE B				1215		1015
	1 Stanseel B				191 -		1015
	C. Parameter						
Nith open	er tannen 197 marit 1994 - January Tannen I 1970 - Dalla		Аррелинт				
and speed	17 (1993) 1992 - Mallinard I Mallin I 1787-1803	<b>.</b>	Appenders	194	14 14		
and speed	17 (1993) 1992 - Mallinard I Mallin I 1787-1803					-	
and mand	17 (1993) 1992 - Mallinard I Mallin I 1787-1803				41 4		
and mand	17 (1993) 1992 - Mallinard I Mallin I 1787-1803				- 40 - H	-	
and mand	17 (1000) 1990 - Antoniouri I Antonio 1787-1800 <b>8</b>				41 H		
and mand	17 (1000) 1990 - Antoniouri I Antonio 1787-1800 <b>8</b>				41 4	1.0	
and mand	17 (1000) 1990 - Antoniouri I Antonio 1787-1800 <b>8</b>				40 H		
and mand	17 (1000) 1990 - Antoniouri I Antonio 1787-1800 <b>8</b>					100	
and mand	17 (1000) 1990 - Antoniouri I Antonio 1787-1800 <b>8</b>				4. 4		
and mand	17 (1000) 1990 - Antoniouri I Antonio 1787-1800 <b>8</b>						
and mand	17 (1000) 1990 - Antoniouri I Antonio 1787-1800 <b>8</b>			•••	41 4	•	
and mand							
and speed							
and mand							
and speed							
and mand							
and mand				<b>174</b>			
and mand				<b>174</b>			
and mand					40 H		
and speed				<b>174</b>			

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



Agent-Based Computational Economics

# Why Economics?

	) = 🕨 II 🗰 👂	Broase Automs		onligate		
Nine			Unitelier	and the second state		
transfeel		ALC N.	Charley an	Character		
	I Darrer 9	and and		48h Carm	1100.00	# 11 m 1001
America	1 Demonred 1			46h Deeno		905
	20 Thinseel B.			483. Oraliseria	1603 0 5	141
Congrantie	There is		80 200	460. Dates	11151	955
	There is		80 200	483. Hoopigniner	1275	475
	Tempered 1					35 835 94X
	Tannerei B.				1010 0	a aa 100%
Quint	I I I Landeri B.			48h Colombula	1000 0	1015
	I Tamere B				10006	000 1015
	1 Daamasel B.				0000	1015
Nicellaneess	10 (Tanner I		60	48h Gelonebula	1010 0	6 65 101X
Querr	10 [Tansed L			483- Gransfula	100 2	1015
	10 (Tanard L			48h Getshebuts 48h Lauskepr	1012-0	1015
			203	and and he per	152 0	00 00 TOTC
	Show stacks				. 14	Nest P
	Province Province Province Province Province		Approtect			pile sec
	(17 March 19				ia ija	
	() (* 1000) 100 - 1000 (* 1000) 1770-004				te tje	
	() (* 1000) 100 - 1000 (* 1000) 1770-004			- 19 <b>4</b>	te tje	
	() (* 1000) 100 - 1000 (* 1000) 1770-004				ia ila.	
	() (* 1000) 100 - 1000 (* 1000) 1770-004				ia ila.	
	() (* 1000) 100 - 1000 (* 1000) 1770-004				- 41 H	
	() (* 1000) 100 - 1000 (* 1000) 1770-004				4: 4	
	() (* 1000) 100 - 1000 (* 1000) 1770-004				941 94	
	() (* 1000) 100 - 1000 (* 1000) 1770-004					
	() (* 1000) 100 - 1000 (* 1000) 1720(204)			9 99 99 9		
	() (* 1000) 100 - 1000 (* 1000) 1720(204)					
	() (* 1000) 100 - 1000 (* 1000) 1720(204)			السحد 8	90 - 190 	
	() (* 1000) 100 - 1000 (* 1000) 1720(204)			السحد 8		
	() (* 1000) 100 - 1000 (* 1000) 1720(204)			السحد 8		
				السحد 8		
				السحد 8		
	() (* 1000) 100 - 1000 (* 1000) 1720(204)			السحد 8		
				السحد 8		

- 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

・ロト ・同ト ・ヨト ・ヨト



# LeBaron's Model of Stock Price Volatility Rules of the Simulation (continued)

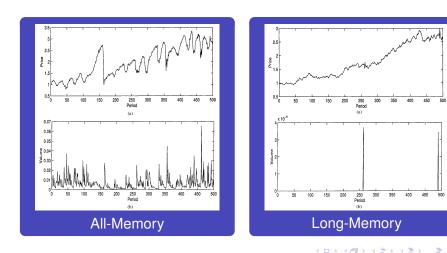
- Periodically, the strategies are evolved using a genetic algorithm, first by removing all strategies that were not used recently, then by randomly applying one of the three following criteria:
  - Change one weight (selected at random) in the strategy
  - Replace one weight (selected at random) in 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

Implementation

Results ○ ○○● ○○○○○○

Agent-Based Computational Economics

### LeBaron's Model of Stock Price Volatility



Williams, Agent-Based Modeling

# 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

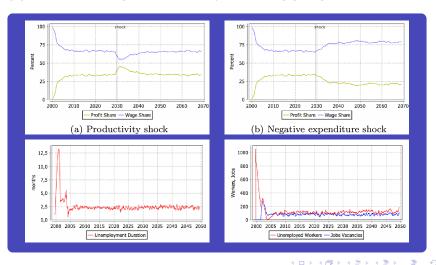
# Seppecher: Wage Flexibility and Aggregate Demand

### 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

Agent-Based Computational Economics

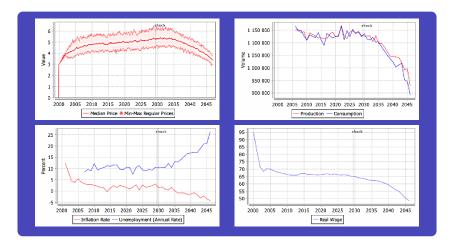
### Seppecher: Wage Flexibility and Aggregate Demand



Williams, Agent-Based Modeling

Agent-Based Computational Economics

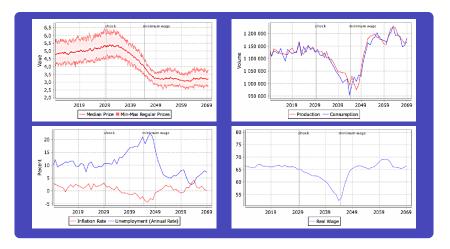
### Seppecher: Wage Flexibility and Aggregate Demand



Implementation

Agent-Based Computational Economics

### Seppecher: Wage Flexibility and Aggregate Demand

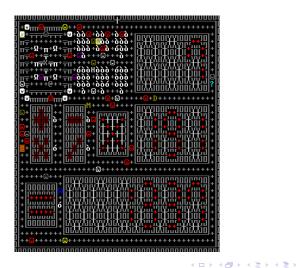


Williams, Agent-Based Modeling

## 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



æ