

Modelling on the Edge of Chaos: Cellular Automata and Agents Representing Complex Dynamical Systems and Building Structures

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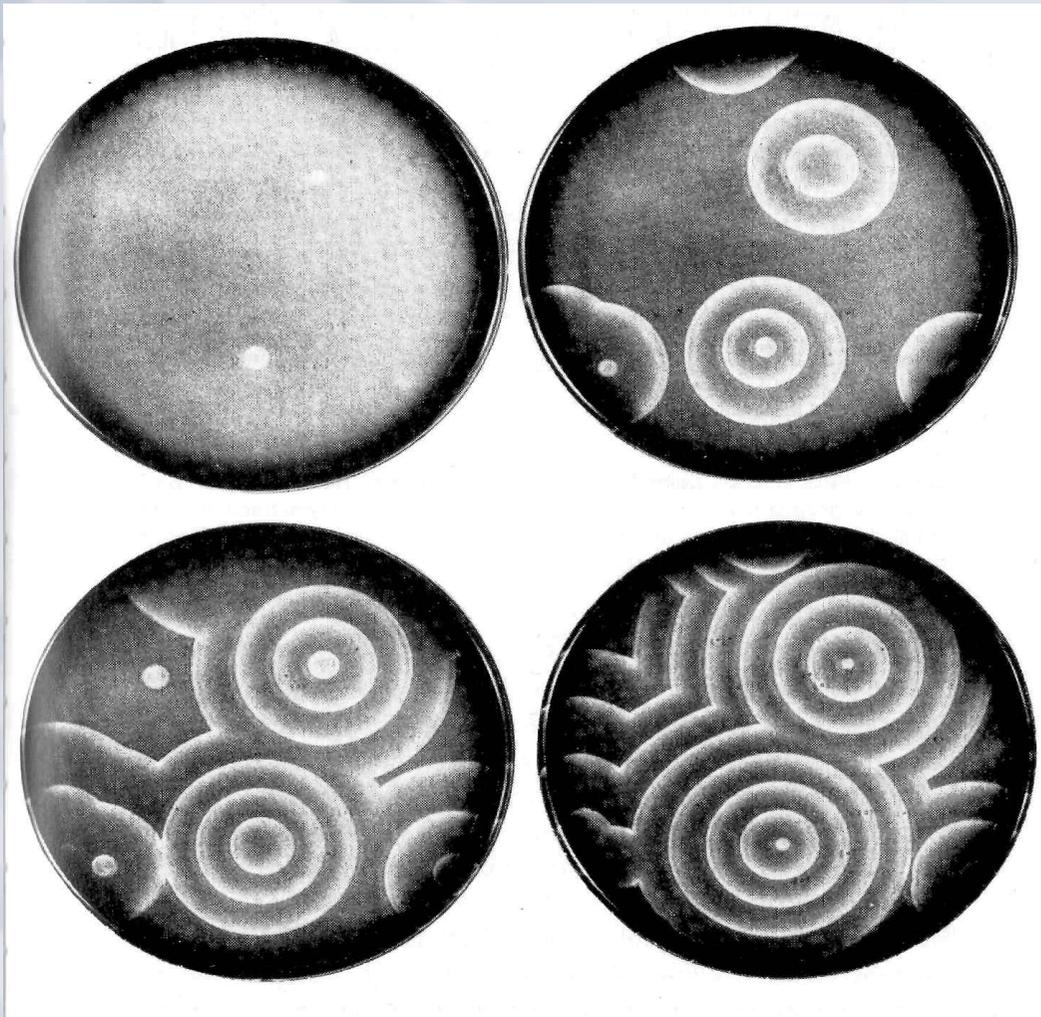
Introduction

- **What I am**
 - Chemist
 - Computer Scientist
 - Interested in
 - Complex Systems
 - Structure Building
 - Epistemology
 - ...?
- **What I am *Not***
 - *A Mathematician*

Content

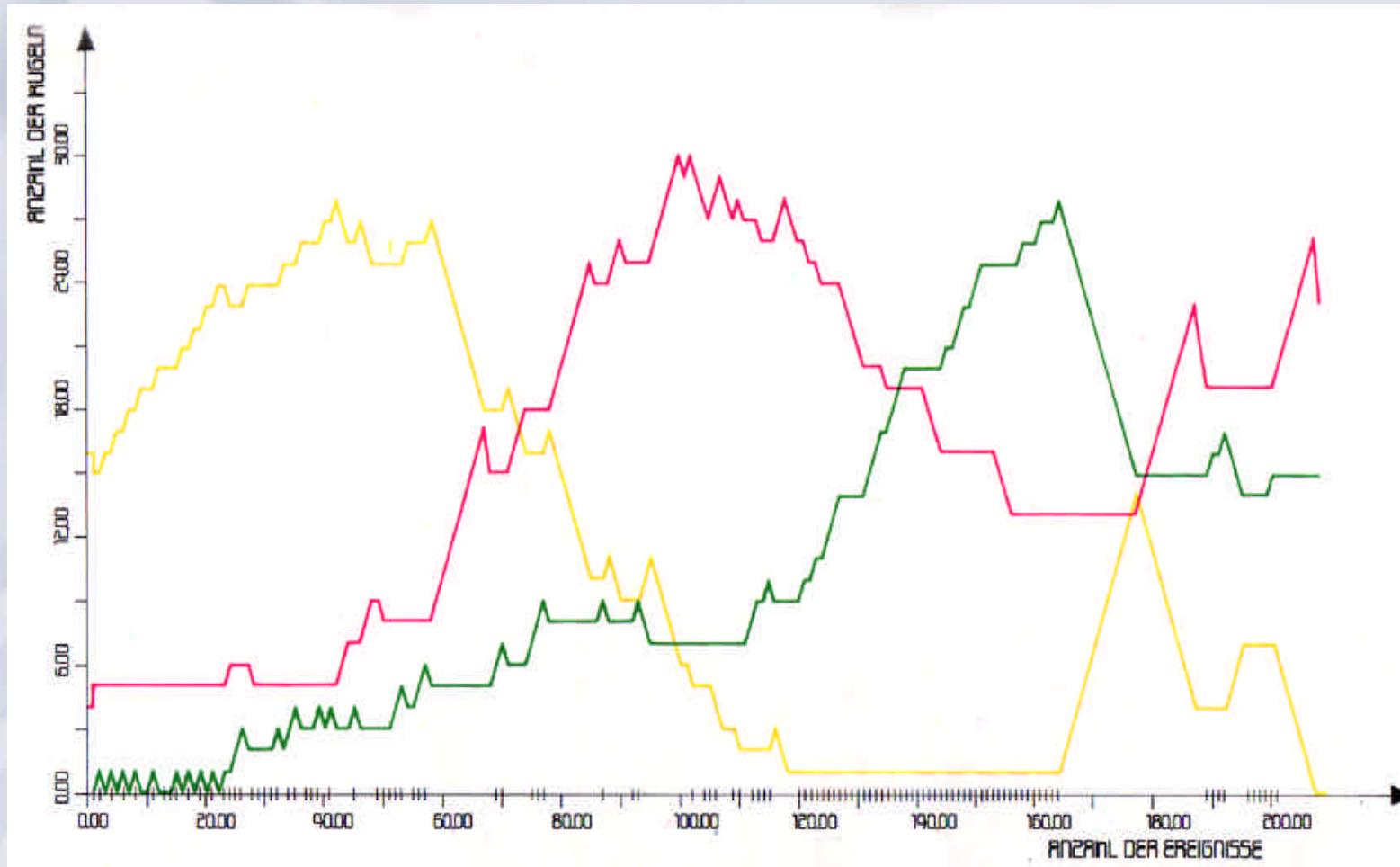
- **Some Reflexions about**
 - Complex Systems
 - Structure Building
- **Roots of the Cellular Automata Idea**
- **Complex Systems**
- **Hands On: Building Cellular Automata**
- **Behaviour of CAs**
- **Applications...**
- **... after the Hype**
- **Agent Based Systems?**

Complex Systems - Structures



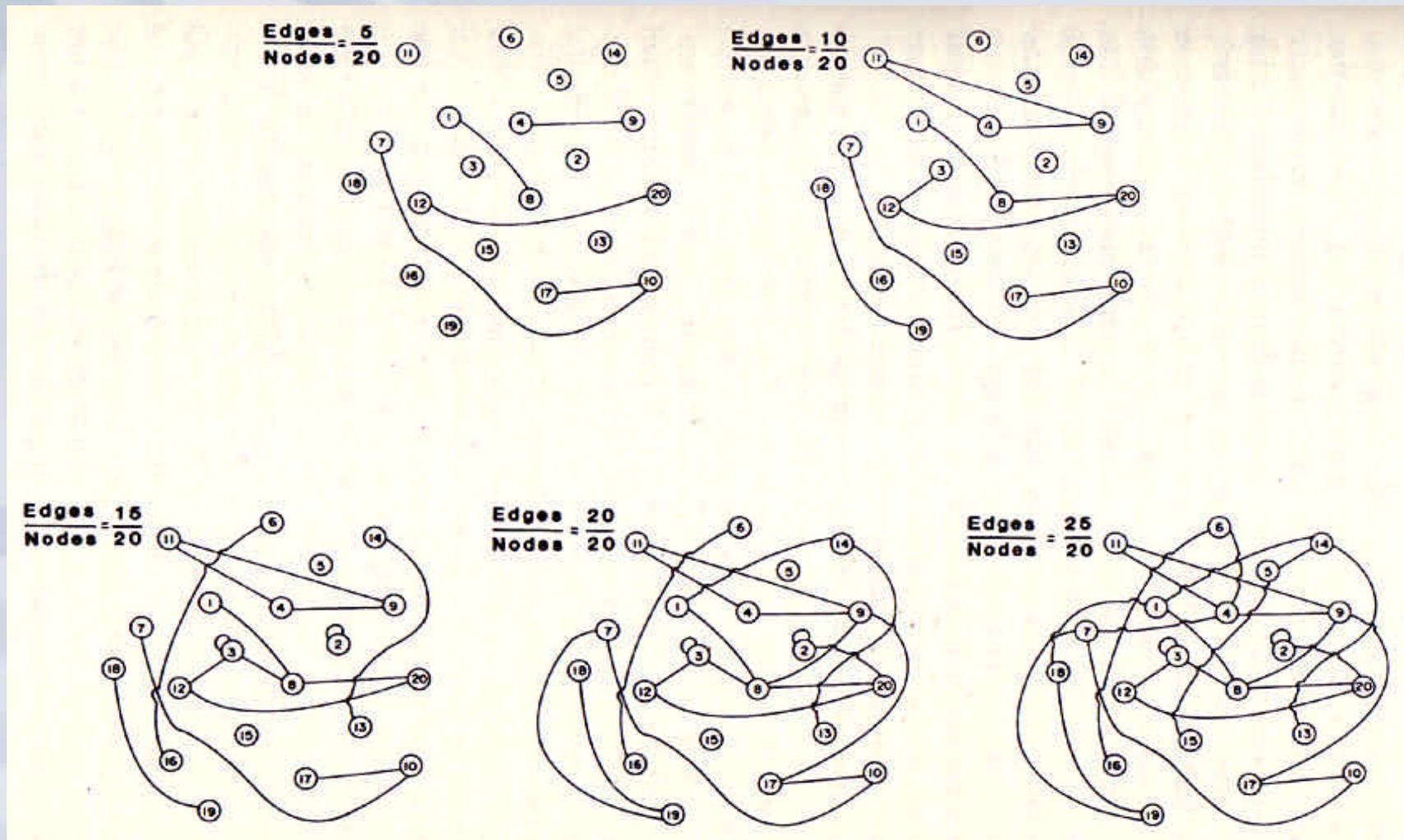
Belusov Zhabotinsky
Reaction

Predator / Prey

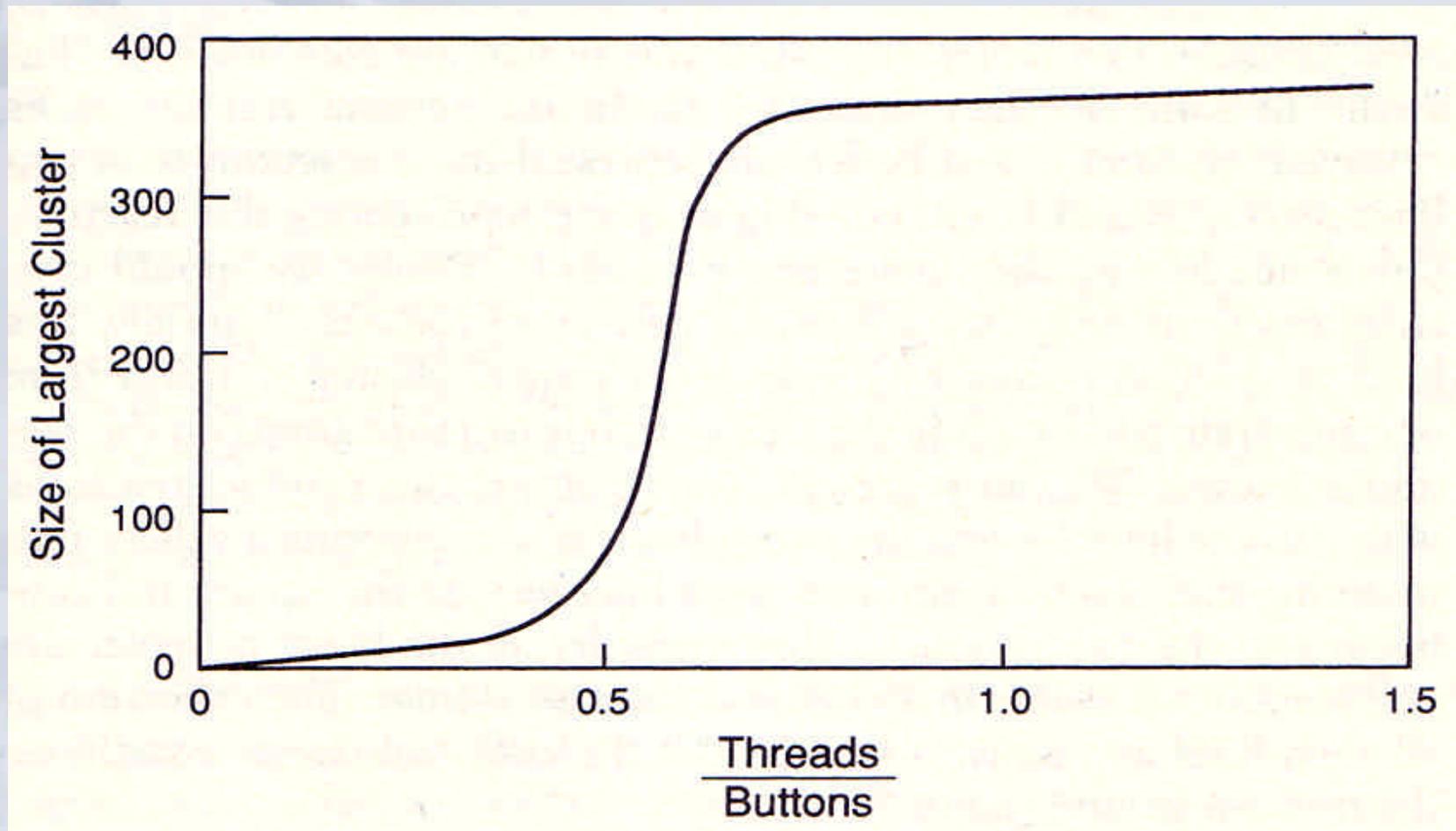


(Manfred Eigen)

“Cristallisation” / Phase Transitions



Phase Transition



(Stuart Kauffman)

Root Ideas of Cellular Automata

- **Theory of Computation (Alan Turing)**
- **Automata Theory**
 - John von Neumann
 - Stanislav Ulam
 - John Horton Conway – “The Game of Life”
- **Cellular Automata are *Turing Complete!***
- **Simulation of Complex Systems by Interaction of using “Simple” Rules**

Complex Systems

- 3 Body Problem (Henri Poincaré)
- Weather Forecast (Edward Lorenz)
- Uncertainty Relation (Werner Heisenberg)

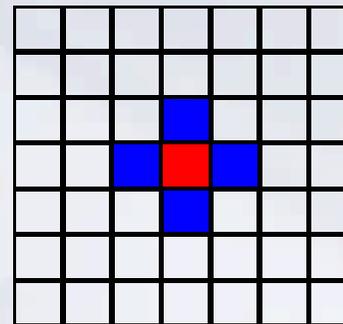
Complex Dynamical Systems often show Huge Effects on Small Changes in the Starting Condition of the Model

Modelling Approaches

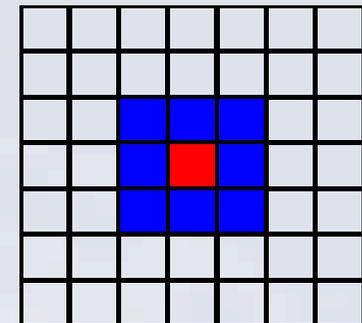
- **Top Down**
 - Traditional
 - Differential Equation
- **Bottom Up**
 - Simulation using Simple Rules
 - Complexity Emerges by Interaction

Building Cellular Automata

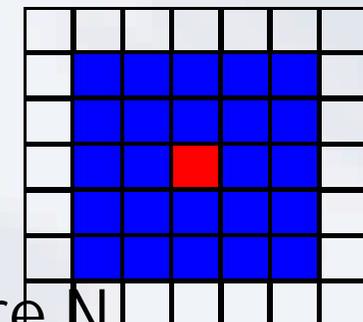
- The Cell
- The Lattice
- Neighbourhoods
- Transition Rules
 - Explicit
 - Totalistic
 - Legal



von Neumann N.



Moore N.



Extended Moore N.

Mathematics

see Handouts...

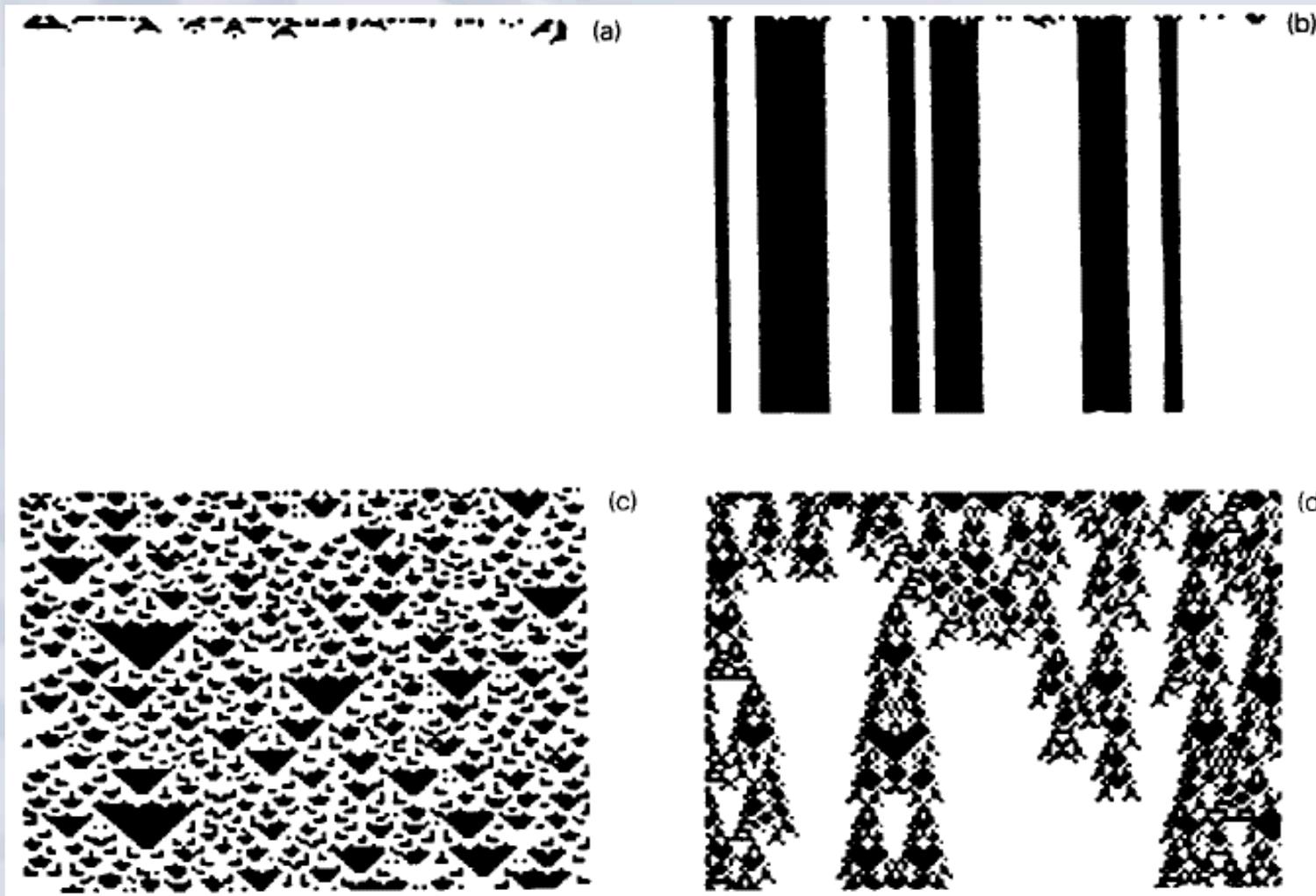
Algorithm Summary

- ***CAs develop in Space and Time***
- ***Discrete Simulation Method***
- ***Cells Arranged to n-dimensional Lattices***
- ***Finite and Discrete Cell States***
- ***Cells have Identical Properties and Transition Rules***
- ***Future State of Cell only Depending on***
 - *Neighbourhood of Cell and*
 - *Defined Transition Rules*

Behaviour of CAs

- **Universal Computation (capable to perform any finite algorithm)**
- **Classes**
 - 1: Limit Points
 - 2: Limit Cycles ($0 < L < 0,3$)
 - 3: Chaotic/Strange Attractors ($L \sim 0,5$)
 - 4: More Complex Behaviour (Univ. Comp.) ($L \sim 0,3$)
 - “On the Edge of Chaos” the Lambda Parameter

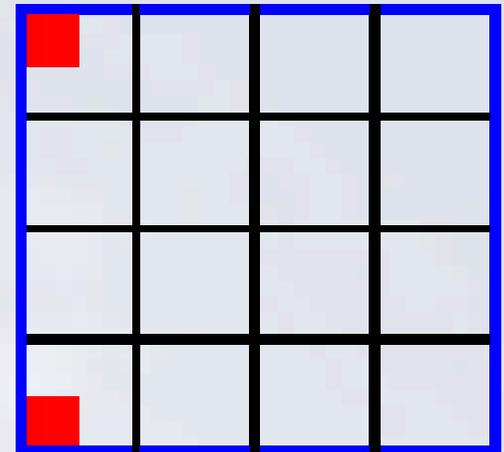
Behaviour – Illustration



(Stephen Wolfram)

Applications

- Game of Life
- Billiard / HPP, FHP - Gas Models
- Ising Model
- Self-Reproduction
- Chemical Waves (Belusov-Zhabotinsky Reaction)
- Reaction-Diffusion Systems



Game of Life

- a cell that is dead at the time step t , becomes alive at time $t+1$ if exactly three of the eight neighbouring cells at time t were alive.
- a cell that is alive at time t dies at time $t+1$ if at time t less than two or more than three cells are alive.



After the Hype...

- **Rich “Theoretical” Results (Automata Theory)**
- **But, did CAs replace Differential Equations in Modelling... ?**
- **Disadvantages of CAs**
 - Simple Rules but: How to find the Right Ones?
 - Scaling Problems
 - Various Practical Problems (Constant # of Particles...)
- **New Ideas?**

Agent Based Systems

- **(Autonomous) Software Agents**
- **New Software Engineering Paradigma**
- **Agent Modelling**
- **Differences to CAs?**
 - Not the Lattice is in the Center but
 - The Individual and the
 - Interaction, which can be more Complex and “Realistic”

Recommended Reading

- Gerhardt M., Schuster H. (1995), *Das digitale Universum - Zelluläre Automaten als Modelle der Natur*, Vieweg, Braunschweig/Wiesbaden
- Gardner M. (April 1970), *The Fantastic Combinations of John Conway's New Solitaire Game of "Life"*, *Scientific American*, 223:4, 120-123
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- Riedl R. (1985), *Evolution und Erkenntnis*, Piper, München
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- Kauffman S., *At Home in the Universe: The Search for Laws of Self-Organization and Complexity*, Oxford University Press (1995)

Thank You... Still Questions open?

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**“Wenn sich der Mensch, die kleine Narrenwelt,
gewöhnlich für ein Ganzes hält,
Ich bin ein Teil des Teils, der anfangs alles war,
Ein Teil der Finsternis, die sich das Licht gebar”
(Mephistopheles, Faust I, 1347)**