Complex Systems Theory

a paper by Stephen Wolfram

presented @ Dallas Papers We Love

Nik Clarkson 3/2/2015

Stephen Wolfram

- Wrote 3 books on particle physics by age 14
- published a widely cited paper on heavy quark production at 18
- Became faculty at Caltech at age 21
- 1985 tonight’s paper
- 1988 released Mathematica 1.0
- 1992 – 2002 A New Kind of Science
- 2009 Wolfram Alpha – Computational data

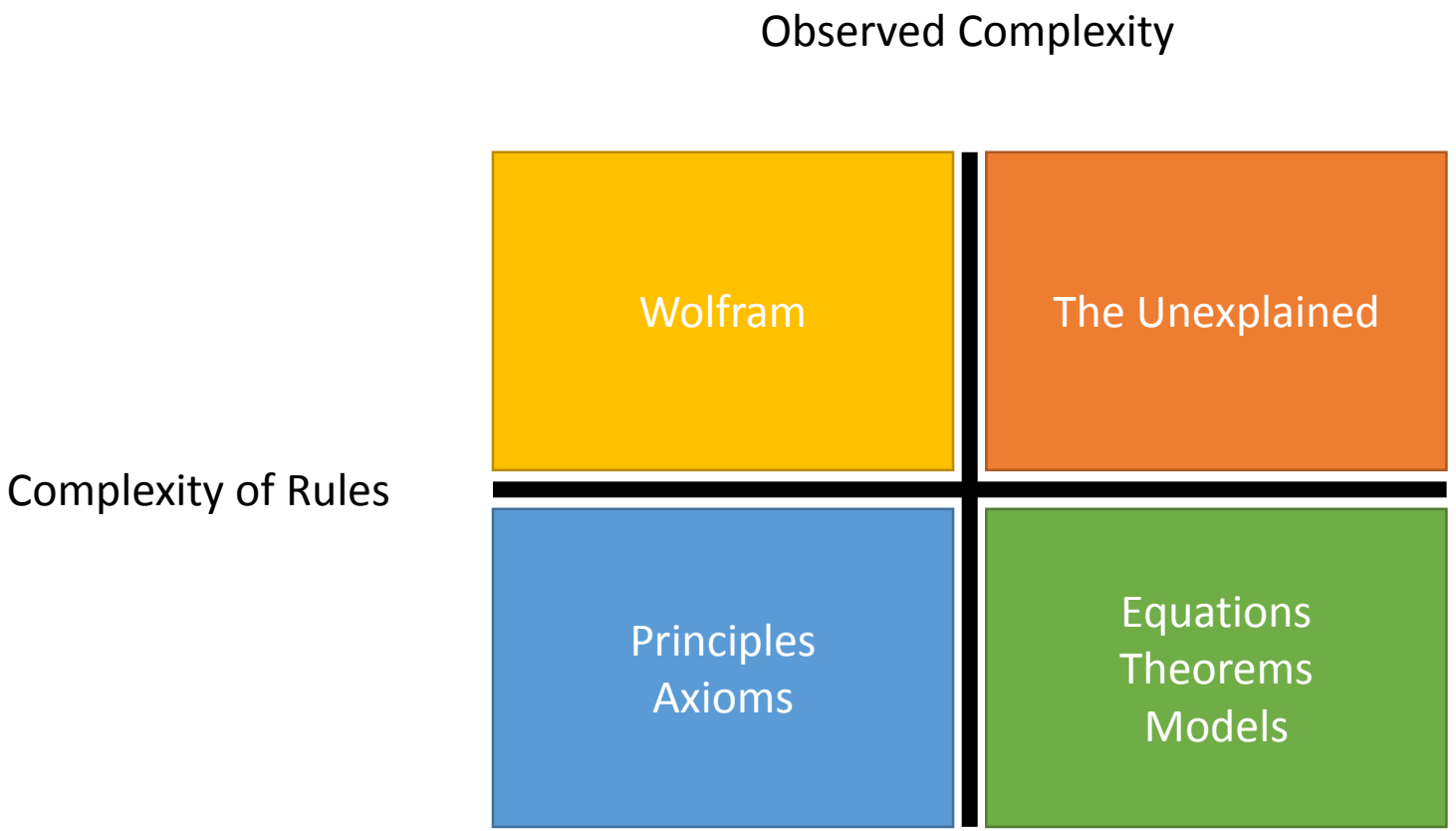
Why is this paper interesting?

- Insight into Wolfram's thought process
- The birth of a New Kind of Science

Phenomenon of great complexity

- In the natural world
  - Bees
  - Birds
  - Minerals
- In the artificial world
  - Networks
  - Facebook groups
  - Optimization algorithms

Is the answer simplicity?



in search of a generalized governing law

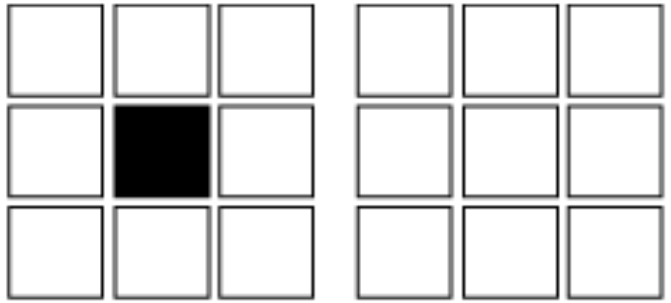
Cellular Automata

- A grid of cells
- A list of possible states for a single cell
- A collection of rules governing state transitions

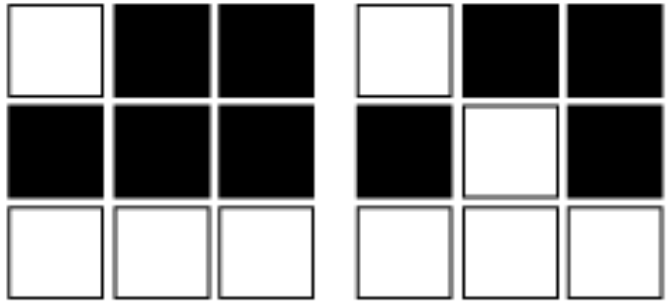
Conway's Game of Life

- John Horton Conway – October 1970 Scientific American
- Each cell has eight neighbors
- The Rules
  - Any live cell with fewer than two live neighbors dies, as if caused by under-population.
  - Any live cell with two or three live neighbors lives on to the next generation.
  - Any live cell with more than three live neighbors dies, as if by overcrowding.
  - Any dead cell with exactly three live neighbors becomes a live cell, as if by reproduction.

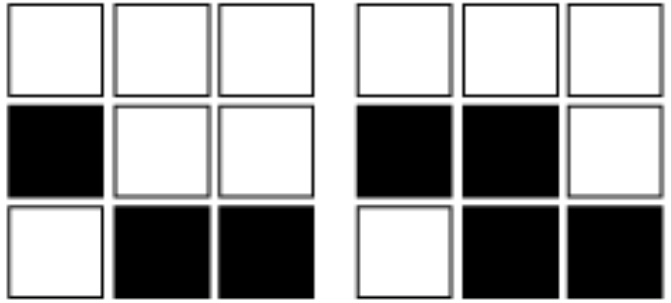
Conway's Rules



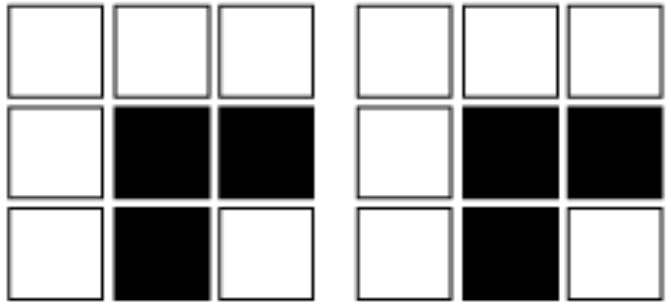
Loneliness
A cell with less than 2 adjoining cells dies.



Overcrowding
A cell with more than 3 adjoining cells dies.



Reproduction
An empty cell with more than 3 adjoining cells comes alive.



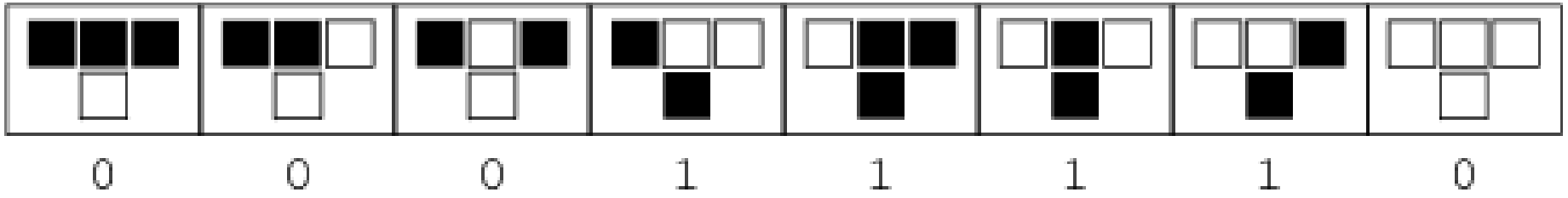
Stasis
A cell with exactly 2 adjoining cells remains the same.

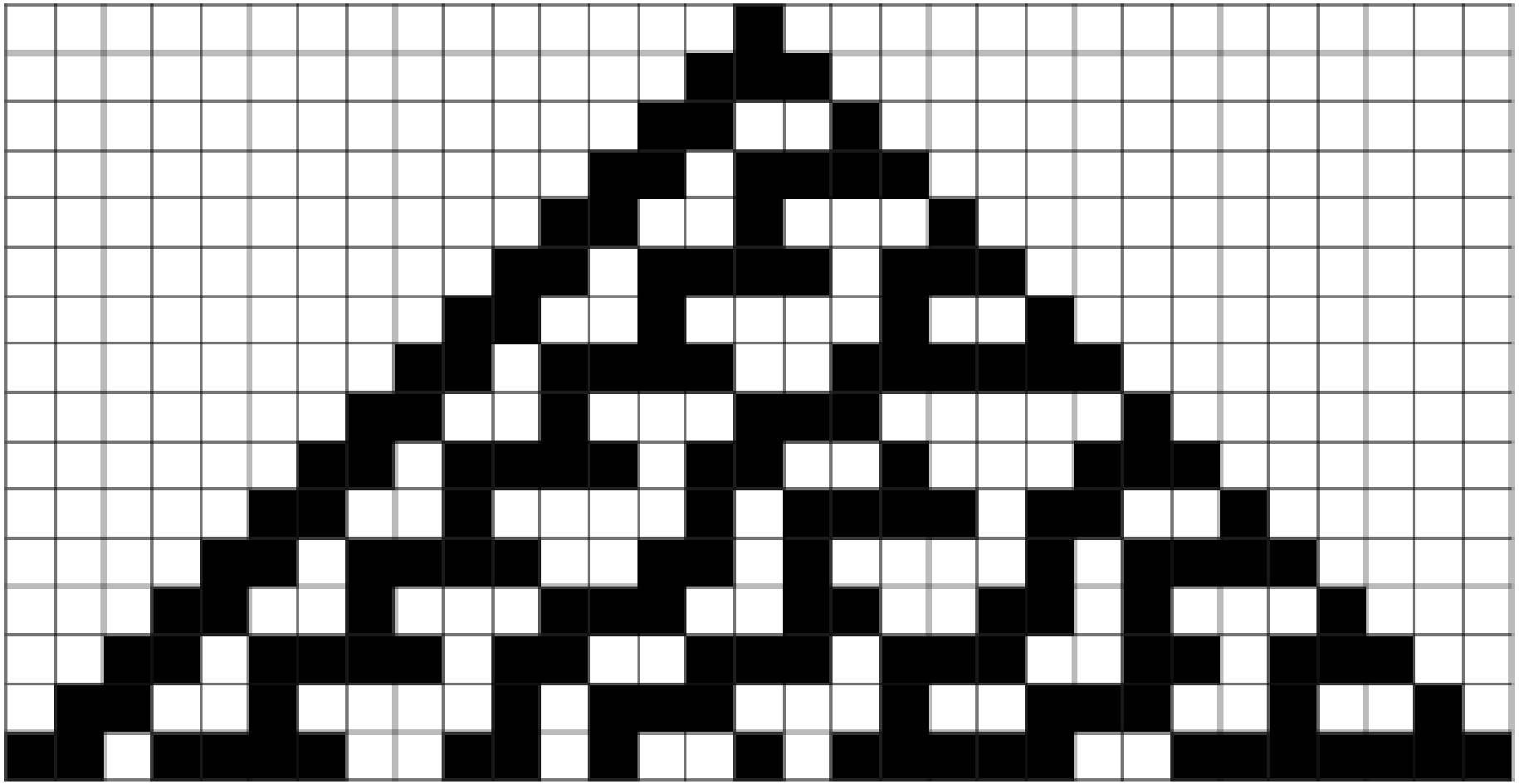
Game of Life

Elementary Cellular Automata

- Only 2 cell states
- One dimension
- One rule

rule 30





Consequence

- The implication that complicated patterns of growth can arise from simple basic processes
  - External Randomness – boat on the ocean
  - Initial conditions – car on a bumpy road
  - Internal complexity generation – Rule 30

Physics & Biology

- Physics typically declares the simplest model the right one
- Biology wants to use the simplest model, but often natural events step in to mess this up.

Stephen's Leap of Faith

"It is only the improbability of a very complicated arrangements have been reached by biological evolution that makes a criterion of simplicity at all relevant. And in fact it may no more be possible to understand the construction of a biological organism than a computer program: each is arranged to work, but a multitude of arbitrary choices is made in its construction."

Experimental Mathematics

- Mathematical rules are formulated and the consequences observed
- Modern computational horsepower makes this more feasible each day
- Wolfram believes this might be as revolutionary as the telescope was to biology.
- In 1985 and even today this field is open to ANYONE!

Dynamical Systems

- State transitions over time
  - Complexity over time
  - Differentiable over time

- Cellular Automata as discrete idealized partial differential equations
  - What!?
  - While the steps are discrete over time this averages out to appear continuous

Evolving Complexity

- Self organization produces complexity over time
  - Dynamical evolution
- Randomness
  - is relative to our knowledge, skills, and models
- Chaos
  - Isn’t necessarily random

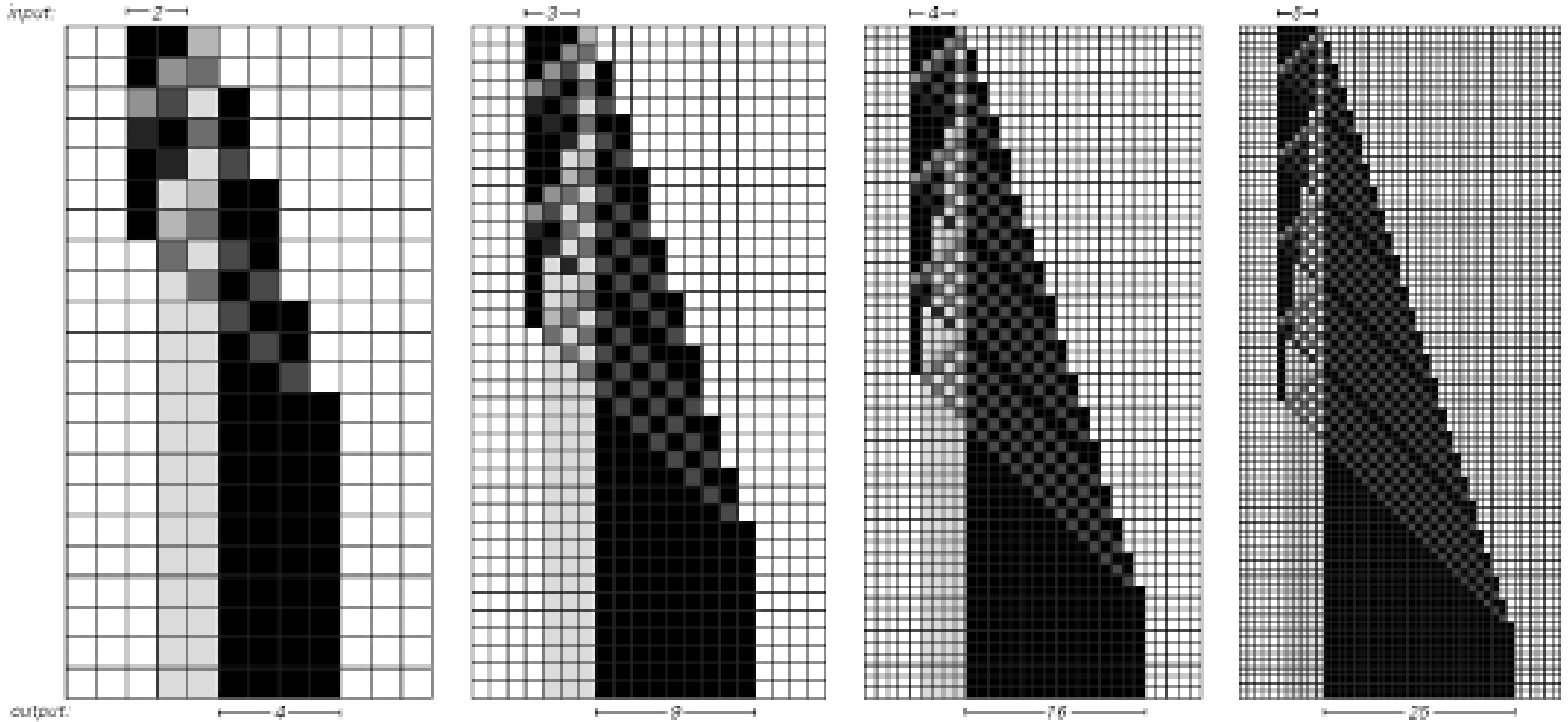
Cellular Automata aren’t just simulations

- They can do computations
- Propagating structures are like signals interacting
- They can act as universal computers

Simple Computation

- IsOdd() Mathematica example

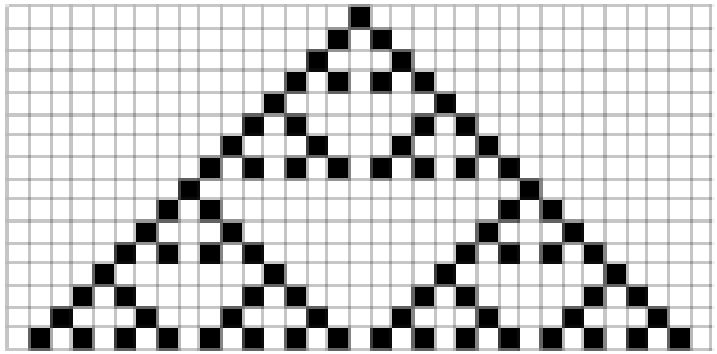
Computing Squares

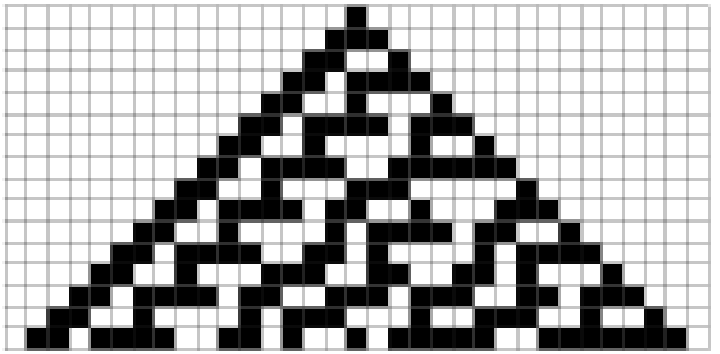


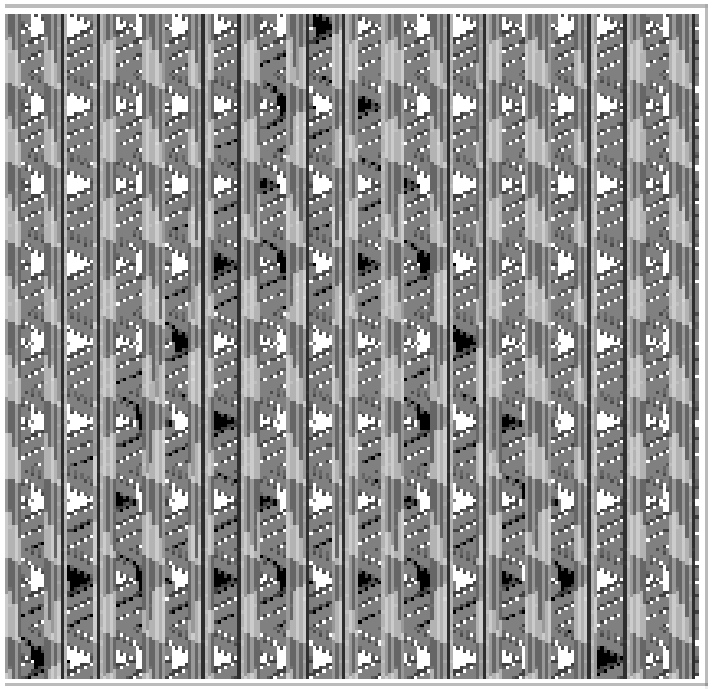
Signals interacting

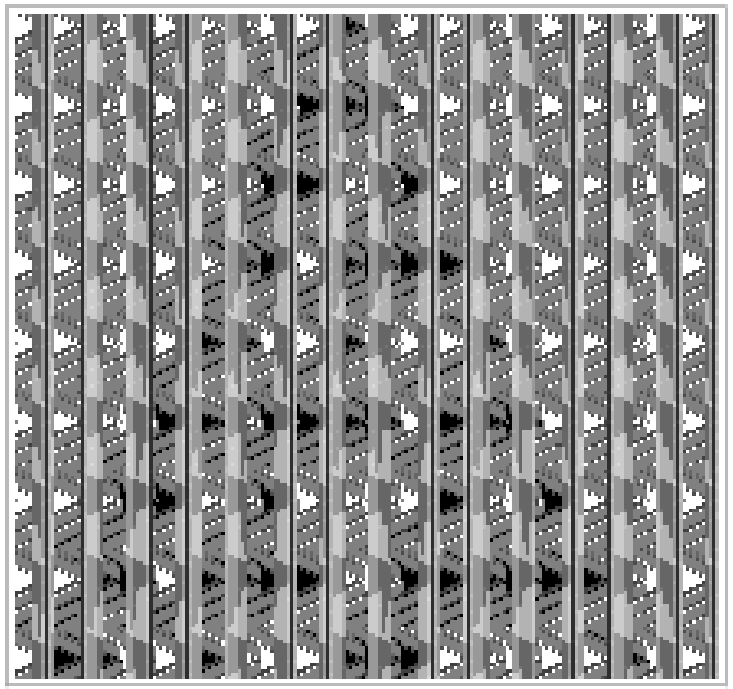
- Golly application prime generator example

Cellular Automata as Universal Computers









Where simulation falls short

- Cannot implicitly simulate
- A computer would have to behave more complex than itself.
- A universal computer cannot one up itself
- Computational irreducible
- Darwin’s search example
- Must use explicit simulation – every generation must be calculated

Wait.. Why did I read this paper then?

- Von Neumann space ship – complexity growth
- Still a new area of study
- Wolfram is searching for new principles
- Quantum computing?

The glue between the disciplines

- What binds physics and biology?

- Twitter: @CaptainArkansas

- Github: https://github.com/armadilloNik/WolframComplexSystemsTheory