A New Kind of Science

by Stephen Wolfram

Chapter 7: Mechanisms in Programs and Nature

Ned Dochtermann; CS 790R, 2/1/2006
EECB Graduate Group, University of Nevada, Reno

Mechanisms in Programs and Nature

- Universality, randomness etc.
- Wolfram's broader contentions
- Comments on Wolfram's contentions

Mechanisms in Programs and Nature

- Section 1: Universality of Behavior
- Section 2: Three Mechanisms for Randomness
- Section 3: Randomness from the Environment
- Section 4: Chaos Theory and Randomness from Initial Conditions

Mechanisms in Programs and Nature

- Section 5: The Intrinsic Generation of Randomness
- Section 6: The Phenomenon of Continuity
- Section 7: Origins of Discreteness
- Section 8: The Problem of Satisfying Constraints
- Section 9: Origins of Simple Behavior

Universality of Behavior

- Examples prior to this chapter have established that complex behavior can be generated by simple rules/programs
- “(T)o what extent is the behavior obtained from simple programs similar to behavior we see in nature?”

pg 297

Universality of Behavior: II

- Vastly different natural systems demonstrate a high degree of similarity
- Simple programs with different rules produce similar behavior
- This leads to the contentions that:

  (1)"(U)niversality exists in the types of behavior that can occur, independent of the details of underlying rules" pg 298

  (2) Unsatisfactorily explained phenomena can be explained via cellular automata

Three Mechanisms for Randomness

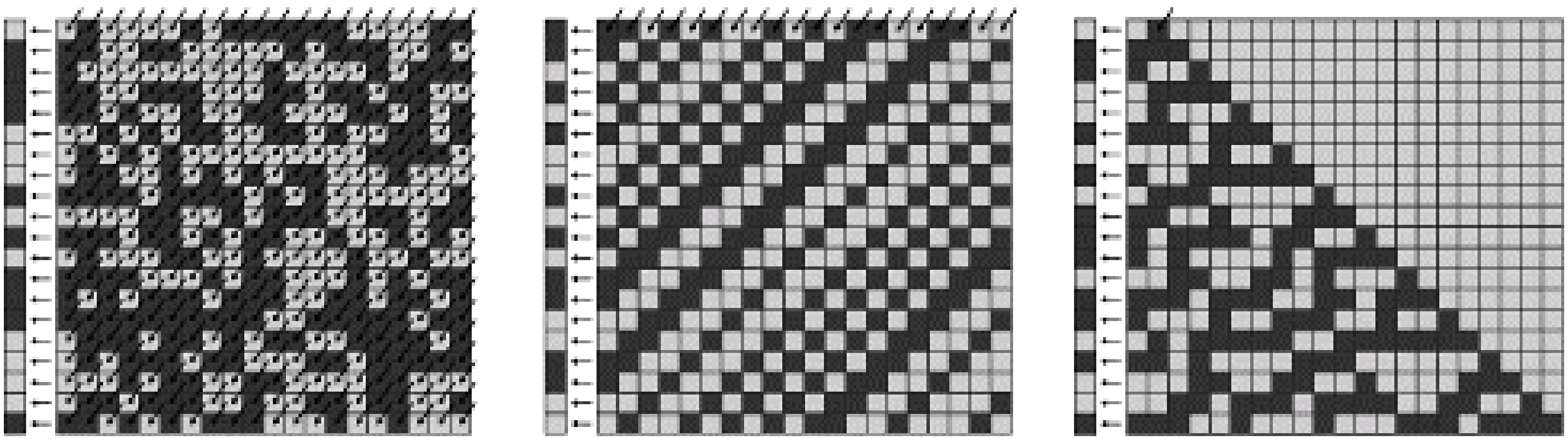
- Randomness in nature is common
- Simple programs suggest three mechanisms that generate randomness:

(1) Randomness is explicitly and repeatedly introduced

(2) Initially random input, deterministic rules

(3) "(S)imple programs can produce apparently random behavior even when they are given no random input"

Three Mechanisms for Randomness



mechanism 1: randomness from the environment

mechanism 2: randomness from initial conditions

mechanism 3: intrinsic generation of randomness

Three possible mechanisms that can be responsible for randomness. The diagonal arrows represent external input. In the first case, there is random input from the environment at every step. In the second case, there is random input only in the initial conditions. And in the third case, there is effectively no random input at all. Yet despite their different underlying structure, each of these mechanisms leads to randomness in the column shown at the left. The first mechanism corresponds to randomness produced by external noise, as captured in so-called stochastic models. The second mechanism is essentially the one suggested by chaos theory. The third mechanism is new, and is suggested by the results on the behavior of simple programs in this book. I will give evidence that this third mechanism is the most common one in nature.

Three Mechanisms for Randomness

(1) Randomness is explicitly and repeatedly introduced

(2) Initially random input, deterministic rules

(3) "(S)imple programs can produce apparently random behavior even when they are given no random input"

Randomness from the Environment

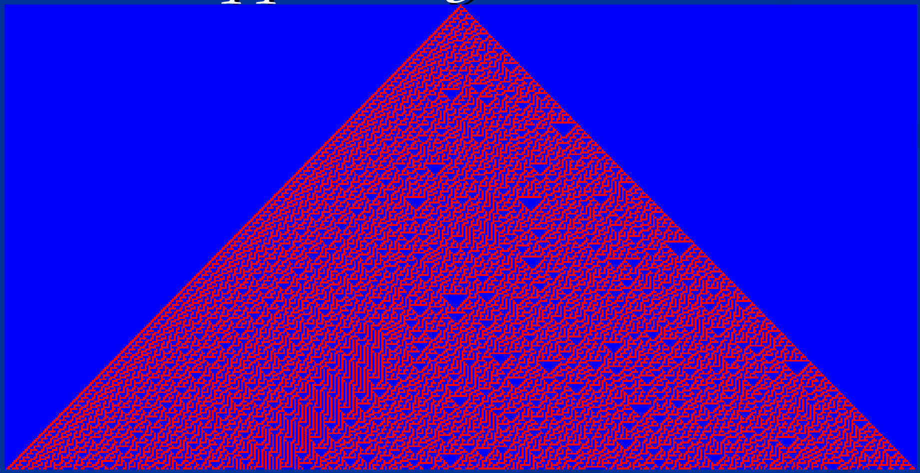
- Examples of random input given:
  - A boat on the water
  - Microscopic, Brownian motion
    - e.g. Spark chambers
- These examples are argued to be fundamentally non-random or tautologies
  - Underlying non-random processes
  - Temporally correlated behavior (e.g. spark chambers)
  - One random source leads to another
  - Require some outside force: ***unsatisfying***

Chaos Theory and Randomness from Initial Conditions

- Randomness in initial conditions can lead to random behavior.
- Contingent on outside forces (randomness from environment, e.g. previous section)
- Therefore ultimately unsatisfying
- Examples given: kneading process, light reflection, sphere moving across a surface, three body systems

The Intrinsic Generation of Randomness I

- Both the previous mechanisms are unsatisfying as they require some "other" force
- "Simple" rules can generate *apparently* random behavior (e.g. rule 30)



- How random?
  - Random enough
  - Pass "most" tests
  - Those it does not, do not matter
  - Fits operational definition of random

The Intrinsic Generation of Randomness II

- Rule 30's center column is the operational definition of random
- This and similar simple rules are more random than historical random number algorithms (e.g. linear congruential generators fail

The Intrinsic Generation of Randomness III

- Observation:

  more complex rules/systems→ more order (order inertia)
- Assertion: the simplicity of rule 30 indicates that this is likely a common route to achieve random behavior
- Discerning between mechanisms
  - Repeatability (neither of the first two mechanisms are repeatable)
  - Robust to perturbation

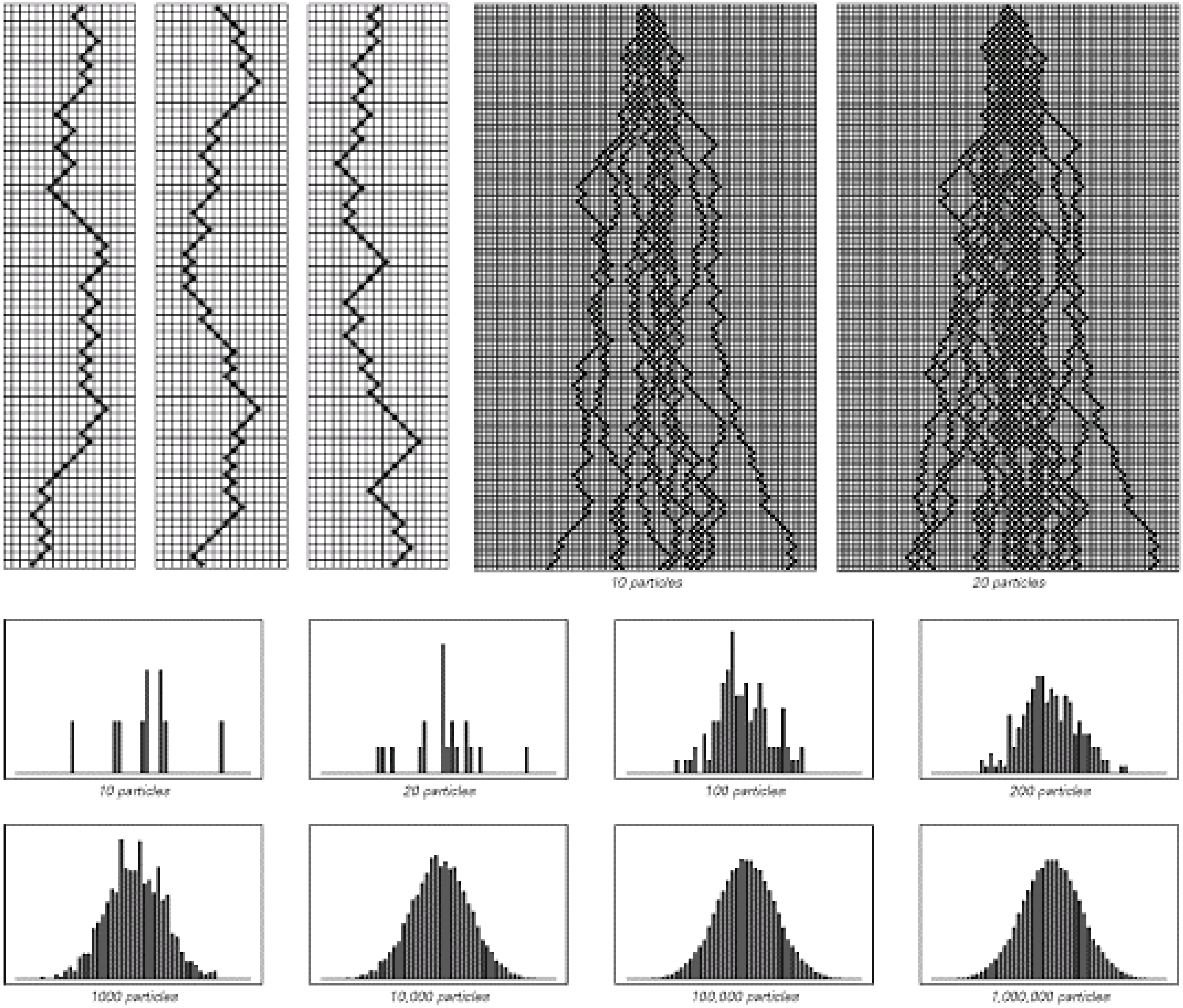
The Phenomenon of Continuity I

- Natural phenomenon display continuity, hence the appeal of continuous equations
- Can you get the same continuity with a fundamentally discrete system (CAs)?

Yes

The Phenomenon of Continuity II

- "smoothness" is an artifact of scale and randomness (e.g. random walks, central limit theorem)
- requirement: continuous patterns of growth observed when small-scale random change occurs at a much higher rate than the overall growth rate



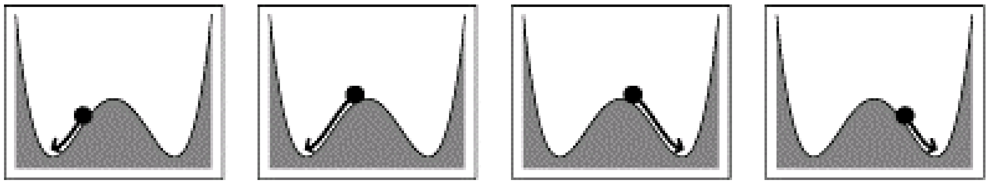
The distribution of positions by reached particles that follow random walks. The top left shows three individual examples of random walks, in which each particle randomly moves one position to the left or right. Even though the individual particles are discrete, the pictures show that when a large number of particles are considered, the overall behavior obtained seems smooth and continuous.

Origins of Discreteness

- Is the discrete character of cellular automata at all representative of what is observed in natural systems?

Yes

- Continuous changes can result in discrete output
  - program outputs
  - movement
  - boiling water



A standard simple example of a continuous system in which there is a discrete change in behavior as a consequence of a continuous change in initial conditions. When the ball starts anywhere to the left of the center line, it rolls into the left-hand minimum. But if instead it starts on the right, then it rolls into the right-hand minimum. There are many systems in nature that follow the same general form of mathematical equations as those that describe the energy and motion of the ball.

The Problem of Satisfying Constraints

- Typically you cannot move from constraints to patterns efficiently
- Purely random processes are unlikely to fulfill constraints as well
- Systems progress iteratively but get stuck, require some random element to escape
- Complex patterns with constraints are more efficiently produced through preset structure and rules

Origins of Simple Behavior

- Three types of simple behavior
  - Uniformity
  - Repetition
  - Nesting

Chapter 7: Conclusions

- Given that simple rules produce complexity, randomness, robustness, continuity and discreteness; it is parsimonious to infer that such simple rules underlie physical demonstration of those phenomenon

Comments

- Constructs a rhetorically appealing argument within a generally consistent logical framework

- Wolfram generally overextends his assertions due to lack of crucial examples and frequently commits logical fallacies in making his argument
  - e.g. most frequently he erects strawman arguments
    - his discussion of natural selection and evolution
    - similar caricatures of other phenomenon and causal explanations?