Comments on Wolfram's **A New Kind of Science**

Review by D. A. White

Wolfram, Stephen. **A New Kind of Science**. Champaign, IL: Wolfram Media, Inc., 2002. This is another blockbuster book by Stephen Wolfram, the creator of **Mathematica**. The title is ambitious to say the least. The systematic study of cellular automata -- the main research tool used by Wolfram for his book -- may well become a new scientific discipline. But Wolfram's vision is much broader. He feels he has identified some global principles, and he is deeply exploring the boundaries and the interactions between the mental (mathematical) and physical worlds. This makes him a major pioneer in Observer Physics (OP).

A key theme of Wolfram's work is what he calls the principle of "computational equivalence" -- the ability of mathematics to mimic the physical world. If I understand him correctly, he means by this idea that as a system grows in complexity, there is a threshold beyond which all systems behave the same. (Does this mean that God -- and the aliens -- are no smarter than we are? Is this anthropomorphic jingoism? Or does it just mean that everyone is equally good at making a mess?) Perhaps Wolfram is talking here about the limit where complexity becomes pure randomness. Wolfram's idea of "Computational Irreducibility" refers, it seems, to the notion that at some point any model of a system essentially reproduces the system in another medium with the same complexity. Related to this is the mathematical notion of "universality" -- that a certain program can be set up to emulate a whole class of programs. A similar idea is the notion that you can emulate algebra with geometry and vice versa.

Wolfram's starting point in the creation of his "New Kind of Science" was his discovery that very simple programs can produce great complexity and even randomness. This is not really a new discovery. Mathematicians have known this since the discovery that a simple ratio such as pi is an irrational quantity that generates a decimal with an infinite string of random digits. Linguists are familiar with ways to generate randomness (or at least great complexity) from simple grammars, and more recently the fractal and chaos people have made a great deal of progress generating infinite complexity with simple mathematical structures such as the Mandelbrot set. (In OP we discuss the example of the growth equation with the Verhulst factor included so as to make the system nonlinear.) What may be special about Wolfram's approach is the importance and generality he attaches to this principle. Its flowering as a principle definitely is a product of the computer age.

But, although Wolfram may not be the first to notice that a new kind of science is emerging, he is definitely one of the significant pioneers in this new science.

Wolfram has developed some wonderful ways of systematically exploring the behavior of computer programs. This is an extension of what people were already doing with computers to model behaviors of systems. But Wolfram has carried it to a more abstract and general level as a discipline in its own right. Like Mandelbrot in his breakthrough fractal research Wolfram uses the computer's powerful graphics capability to explore simple program structures, exploiting the human capability to analyze data in parallel through visual scanning of patterns. Combining this with the computer's high-speed iterative power gives awesome results. He creatively uses the identity of geometry and algebra the same way that Mandelbrot and others have to speed his research and make it more accessible. Pictures are worth a thousand words.

Wolfram has come up with a general typology of system behavior with regard to its most general level of organization. He identifies four classes. There are really five classes of system "equilibrium" that show increasing levels of complexity, but Wolfram combines the first two. He really should keep them separate, because perfect homogeneity and total random mixing are the opposite limits of a spectrum. Also, for a nice symmetry in his taxonomy, he should divide Class 4 into periodic islands and nested islands.

Class 0:	Homogeneity without change (total simplicity)
Class 1:	Repetition (periodicity, oscillation); more generally -- "linking"
Class 2:	Nesting (periodicity with embedded structures); fractals
Class 3:	Randomness (chaos)
Class 4a:	Local Structures (chaos with local islands of repetitive order)
Class 4b:	Local Structures (chaos with islands of nested structures)
Class 4c?	Local Structures (chaos with local islands that migrate)

Classes 0, 1, and 2 exist in blank (homogeneous) environments. Classes 3, 4a, and 4b exist in chaotic (random) environments. Of course we can also add mixing of repetition and nesting at both levels (homogeneous and chaotic). There may also be a further distinction of inanimate and animate creatures at the outer regions of both levels unless such phenomena only occur in Class 4. We also do not know if animate forms are endemic and/or exclusive to class 4 or not. But obviously they do not appear in class 0, and, depending on point of view, may not appear in classes 1 and 2. For example, vertical stripes can be seen as periodic and nonmoving, whereas the same stripes tilted diagonally can be seen as migrating "non-locally" in the same way as the migrating islands of class 4. Plaid squares tilted form crisscross hatches like his Rule 110. These can be regular or irregular. If we have a random field of black and white squares, presumably we could find a viewpoint that would neatly separate the two into two nice classes. For example, if you mix salt and pepper in a jar, you can add water, dissolve the salt, strain out the pepper from the salt water, and then allow the water to evaporate, leaving the salt and pepper nicely re-separated. The water acts as an attractor that shifts a class 3 system into a class 1 system.

Wolfram notes, as the chaos people do, that randomness can simplify by means of "attractors". Thus reversibility is possible for all systems, but exact path reversibility only occurs in periodic, nested, or pseudo-random (not pseudo-periodic or chaotic) systems. Homogeneity and randomness both wipe out path information, but you still can go back and forth from homogeneity to randomness. You just have multiple possible pathways -- a fairly obvious condition.

Wolfram has noticed that Class 4 systems have the interesting property of non-local communication via animated local orderly structures that can move about and interact with other parts of the system. If Wolfram's conjecture that all class 4 systems have animation is true, that is a major contribution. Unfortunately he does not prove it. He just gives some good examples and makes a conjecture. Rule 110 sometimes produces graphics that look like rigid scattering diagrams. Maybe this is the primordial source of the archetype for the "animal". Some automata just sit still like rocks. Some grow like plants. And some range about like beasts, or maybe just wandering asteroids.

Wolfram's classes are not new. Perhaps his assertion that they are universal and general is new. For example, in grammar the blank page represents homogeneity -- we call it "writer's block". Conjunction is repetition of a grammatical structure, usually with linkage by "and" or "but", or perhaps just with commas. Sentences are periodic grammatical structures. Essays are fractally organized into a theme with chapters, paragraphs, sentences, phrases, words, and letters. So language is highly nested with embedded structures. In literary circles randomness is usually referred to as "creative writing". You never know what the writer is coming up with next. This brings up another dimension to randomness. Just typing random letters or words is NOT creative writing. There's a difference. Creativity comes from unexpected, unpredictable shifts to different levels of awareness or points of view.

You can have particles scattered randomly all over a screen, or you can choose a topic and view it from many different random viewpoints. In other words, the screen is the theme and the particles are the various viewpoints. Local structures come up in language as the use of refrains, asides, digressions, and parenthetical expressions, and themes within a complex framework. In my discussion of decimals (**OP**, chs. 3-4) I give examples of these various classes in number theory. Wolfram might take a look at Hockett's famous article in **Scientific American** (203/3, 1960): "The Origin of Speech." Particularly relevant are the design features of productivity and arbitrariness. You can find a summary of this classic article on the Internet. (Also see **OP**, chapter 1).

In Chapter 11 of **OP** I discuss invariance, starting with the notion of the Hamiltonian and the conservation laws, symmetries, and invariances of physics. Embedded in that discussion is a long section about simple mechanical models such as cams and ratchets that describes a whole range of techniques of using symmetry breaking and phase locking to form localized equilibrium states embedded in larger systems. The range goes from complete homogeneity (obviously self-reversible), to periodicity, to nested structures, to thermodynamically randomized systems, to locally phase locked systems. I also give models of quantum techniques for shifting from one style to another or moving from one localized island to another, including also techniques for preventing island shifting -- non-local or nested phase locking.

Perhaps one of Wolfram's key contributions to Observer Physics is his discovery that with computer experiments you can deliberately **objectify** a precise mental-mathematical expression as a computer program and then systematically **observe** the behavior of the mental construction as a physical phenomenon via the computer output (p. 109.) He thereby extends his defined ideas step by step into physical forms. This is important, because, as debuggers well know, some programs behave in unpredictable ways that one would never guess without exploring the outputs of the programs at some length.

However, just as Einstein's principle of equivalence needs to be "flipped" to "conjugate equivalence", so also the principle of computational equivalence needs to be "flipped" by the mirror lens of certainty/uncertainty. (See Chapter 1 and Chapter 6 of **Observer Physics**.) The outputs of Wolfram's cellular automata programs may seem like mathematical structures, but computer printouts really follow the rules of quantum waveforms. As Wolfram extends the Mental Space into the World Space, the question then arises -- just where is the crossover point between mind and matter?

Wolfram's techniques are reminiscent of the knots Doug Henning could effortlessly slide about on a rope. Wolfram is sliding the Mind-World crossover further in the World direction. A program such as Transcendental Meditation (TM) allows one to slide it in the other direction, and a program such as Palmer's **Avatar** (R) allows you to slide crossovers in any direction you like.

There is a clear threshold at the transition from homogeneity to incipient complexity (i.e., simple systems that modulate). Then there is a continuum of increasing complexity that is only defined by the observer. Then there is a "quantum leap" from complexity to "chaos". Randomness is the limit of infinite complexity -- no rules at all, although, oddly enough, you can embed rules and hierarchies of rules within that background of no rules. This is a major finding of chaos theory.

Wolfram writes in great detail about randomness and complexity, but only on p. 552 does he get around to probing for a good definition of randomness. After pecking at it lamely for a few pages, he ends up with the notion that when something is random, no "simple program" can "detect any regularities" (p. 556). **The irony of this definition arises from his claim that simple programs can generate randomness and complexity.** He asserts, but does not prove, that no simple program can detect any regularities in the object of examination. Also he does not give us a "randomness" test. He's talking about a "regularity" test. Where is his "randomness" test? If I'm right about randomness being a limit at infinity, then there is no randomness test. Randomness is non-local and infinite. It is the field of undefined awareness, the field of all possibilities. You experience that when you transcend in meditation. Maybe transcending is the only test of randomness. (See below for further development of this idea.)

Wolfram notes the apparent similarity of complexity to randomness, and after whacking at that notion for a while, he arrives (p. 559) at the idea that something "seems" complex if we can't extract a "simple description" of it. **This again is ironic in the light of his demonstration of how very simple algorithms can generate extremely complex behavior.** Isn't his thesis telling us that, for example, **Rule 30 is a brief, but complete and precise, description of a certain style of complex, or perhaps even totally random, behavior**? Why doesn't he come out and state clearly that total randomness is the upper limit to complexity? If this is so, then the outputs of any two programs that generate total randomness are essentially identical. If the threshold for the onset of true randomness is at infinity, there may be no finite test for it. On the other hand, the onset of complexity (from simplicity) is finite, but subjective (**observer-defined**.) Palmer (**ReSurfacing**, p. 5) suggests that **something seems complex because it doesn't fit in with what you already believe.** He means by this that complexity is observer-defined. A math professor finds calculus simple, but a grade school student finds it complex. Eventually, after a bit of indoctrination, the student may also find calculus simple. Or he may put some attention on it and figure it out, and then find it simple.

Wolfram asks over and over the rhetorical question: What causes randomness? He finds lots of examples of (1) inherent randomness, (2) systems that perpetuate randomness, (3) and algorithms that generate apparent randomness. But he never answers the question of what it is about the third type -- the randomness generator -- that causes randomness.

In **Observer Physics** I answer the question and provide a definitive experiential model you can test for yourself. Consider, for example, the TM technique. It is a very simple algorithm. Sit down. Close the eyes. Wait a few seconds. Pick up the mantra. Continue thinking the mantra in the effortless way that you have been instructed to use it. . . . This is a very orderly and simple algorithm. What are the results? From time to time the mantra disappears, and you find yourself thinking random thoughts. TM thus appears to be a Class 4 system. It starts with a simple program, but develops into a complex localized structure of fractal versions of the mantra embedded in a background of random thoughts and experiences. Oddly enough, this is a very comfortable and natural experience -- suggesting that it is inherent to our nature. Perhaps we are "Class 4 Creatures".

Wolfram might counter: Well, the random thoughts come from "outside" the system. True enough, Wolfram has a very precisely defined algorithm and implements it in the very controlled and limited environment of a computer. But what is "outside"? The system we are using is consciousness. Does not his principle of computational equivalence proclaim that the randomness generated by a natural phenomenon, or a computer program or a human consciousness, are equivalent? The point here (discussed in detail in **OP** from an analysis of consciousness and attention) is that this "simple" process involves initial conditions that begin in a state of extreme bias (ordinary waking state consciousness, thinking the mantra). Attention is awareness flowing in a particular direction. The direction of attention initially is biased to the mantra. But then it shifts to subtler levels of appreciating the same bias. As the attention gets more and more focused in that appreciation, it actually expends less and less energy and begins to expand. The system relaxes its bias. At some point it passes the threshold of bias and relaxes into a completely unbiased state. In that condition anything is possible. Only the wave function of the body and mind of the individual generates higher probabilities for certain thought events. They function as a sort of background bias, a larger nested island complex of probability in the ocean of total thermal chaos. But the ensuing thought events occur quite randomly -- within the probability guidelines of the system. The same is true of the automaton Rule 30. Wolfram uses Rule 30 as the random number generating "mantra" for **Mathematica**. Who knows? Rule 30 might even be a good technique for meditating.

The principle of relaxation of bias at fine resolutions explains the "quantum leap" and strange phenomena such as the double slit experiment. When a system's bias (boundary) relaxes, its "attention" becomes de-localized. When you go to sleep tonight, pay attention to the process by which your attention de-localizes. Then notice how it re-localizes when you wake up. Try deliberately de-localizing your attention. For example, imagine yourself being vastly bigger than the whole universe, such that the universe is not even noticeable. You get homogeneity. Imagine that you do not exist as an individual, and your will has completely gone to sleep. Stuff just comes and goes willy-nilly. You get randomness within the guidelines of certain wave function patterns. Understanding how attention works explains a great deal of the mysteries of quantum mechanics.

According to Heisenberg, as the (Dx) gets to finer resolution, the (Dp) gets de-localized. When the (Dp) gets to fine resolution, the (Dx) gets de-localized. When the TM mantra gets really, really subtle, the "momentum" of consciousness expands to fill the whole universe. We experience unbounded awareness and then any thought can come up. The attention is not biased toward preferring certain thoughts.

When the momentum of a photon beam is very precisely confined, its position becomes very non-local. The photon beam goes through a tiny aperture (focused direction) and then ends up spraying photons all over the place (unfocused location). Heisenberg's relation says

^ (Dp) (Dx) >= H.

The (>) operator means that both position and momentum intervals can relax their bias and expand, which they do, if given half a chance. Thus, in the double-slit experiment, you get a single photon generating interference with itself as if it goes through both slits -- which it does -- IF you relax the bias that it MUST hold to one path. If you tighten the bias by closing either slit or by trying to measure the photon as it goes by (i.e. monitoring,) then you lose the unbiased interference pattern.

The tiny aperture experiment is microscopic and invokes the Heisenberg relation. The double-slit is macroscopic and just involves the range of relaxation of the boundaries of attention focus. Attention's conjugate partner is a photon. We only perceive photons. Everything else is imaginary. Photons are by nature non-local, but we squeeze their beams (pop qwiffs) by the focus of our attention beams. Scientists puzzle over quantum mechanics because they do not want to take responsibility for their own consciousness. However unfocused your attention is, the photon wave function will meet you at that level of focus. You can only see what you are looking for/at. All the rest is imaginary.

Perhaps the most important insight Wolfram is promoting in his book is something that he gained from working on his **Mathematica** project. Over the past three hundred years mathematics has undergone a process of evolution that resulted in the "liberation" of mathematics -- the realization that all mathematics is an arbitrary game designed by the mathematician. (See Hockett's design feature of "arbitrariness".) Liberated Math is what I call "Observer Math" (OM). Anything goes as long as you are reasonably consistent and have fun. (I suppose the fun part is optional.) Goedel's technique is a good example of using a really imaginative method to do mathematics. Wolfram has seen that this notion of liberation transfers to physics and other disciplines of science as well. He realizes that there is no "right" way to do physics, and physics then becomes an unbounded field to play in. In a nutshell Wolfram has realized (**A New Kind of Science**, p. 5) the principle of Observer Physics that the rules of science can be "rules of essentially any type whatsoever." This is the liberation of science -- something which thoughtful scientists have been aware of for some time, but have not dared to trumpet loudly because of the general population's addiction to the "reality" of reality according to their pet beliefs.

In Chapter 4 Wolfram plays with operations on numbers as automata programs that generate various waveforms. Compare his findings with the ideas presented in the first several chapters of **OP**. In other chapters he considers (5) multidimensionality, (6) randomness as a starting point, (7) the relation between programs and nature, (8) the everyday world, (9) physics, (10) perception and analysis, (11) the idea of computation, and (12) his principle of computational equivalence. He finds that the same classes appear wherever he looks, and decides that they are universal classes.

His chapter on physics is particularly relevant to OP. Here are a few key points that come up.

* He notes that principles such as conservation of energy and equivalence of directions seem unrelated to the behavior of cellular automata but can be mimicked by certain programs. This suggests that they are special cases within a much larger and more general context. The same is true of reversibility. Many automata are irreversible. Our previous discussions of pathways explain why.

* Wolfram notices that lots of automata do not seem to follow the second law of thermodynamics. It should be clear why. He is confusing the Mind Space and the World Space. Automata belong to the Mind Space, even though they can be run on a computer. If they are precise, discrete sets of rules and operations with predictable behavior, it is possible to extend them with certainty as far as you like with no loss of information in many cases. The second law describes the World Space. Wolfram's paper printouts are subject to the second law, but not his pure mathematical algorithms. This is a key point of **Observer Physics** discussed in chapter 1. Confusion results when we lose track of where we as observers stand vis-a-vis the crossover points in a system. Wolfram's real insight here occurs when he turns the situation around and realizes that the second law may be a biased viewpoint that only looks at a select range of possibilities. In other words, the second law may not be as general as many people assume.

* On page 455 Wolfram comments that the darkness of the night sky (Olber's Paradox) is evidence for the expansion of the universe. In fact this is only evidence supporting the belief that the universe is expanding. By shifting viewpoint one easily notices that there is background radiation everywhere. The apparent extreme red shifting of this radiation beyond our visual range may be interpreted as merely a sign of the observer's incredible shrinking viewpoint. As an experiment go out on a clear night and observe the sky. Gently adjust your viewpoint until you can actually perceive that the sky is filled with light. Go back inside and close the door, turn off the lights, and, if you like, put your head under a blanket or go into a closet. (Alternatively you can get a sensory deprivation tank and really do some experiments.) Tune your vision until you can see the light field that persists even when all "external" lights are extinguished or blocked. Where does that light field come from? What do you believe?

* Wolfram believes (p. 468) it will not be possible to find the Great Rule that generates the universe without already knowing it. Well, then he should already know it. Palmer's Theorem, the Fundamental Principle of Observer Physics, states it very simply and clearly with a self-referring fractal formula that automatically generates the universe, or any other universe you might like to explore. You always experience what you believe, unless you do not believe that you do, in which case you do not experience what you believe -- which again demonstrates that you always experience what you believe. **Observer Physics** is a start at unfolding some of the consequences of that principle and showing how it links up to what we already know (strongly believe) about modern physics.

* Wolfram believes that the nature of space-time is a huge nodal network. This is a very interesting idea and worth exploring in the light of other emerging theories such as Nottale's fractal space-time and the notions of OP. In an aside, however, Wolfram notes (p. 476) that there are really only networks of 0-, 1-, 2-, and 3-branch nodes. The 0-branch ones are of course null networks -- that is, nodal dusts. No interactions happen with 1-branch nodes either. 2-branch systems seem trivial. All others are just 3-branch nodes or combinations of 3-branch nodes. Feynman diagrams for QED show only 3-branch nodes: 2 for electrons and one for a photon. In OP we show that the QED Feynman diagrams are really 4-branch systems. Any QED interaction is really a four-wave/four-particle mixing involving, say, two electrons and two photons. The photons have tight trajectories that are read as one. The rule about 3 branching nodes forces the interaction into a ring or bubble structure. This is an example of a phase conjugation quantum bubble. Such a bubble can be of any size. It generates the illusion of space-time. Within the bubble is a region of hyper-space-time. Interactions occur within that bubble at a superluminal speed that I call the Planck Velocity. An observer can choose to operate outside the bubble, or inside the bubble, or on the boundary, or as the whole system, ... A complete QED interaction involves two conjugate 4-branched nodes: for example, two electrons to two photons and then the two photons to two electrons; or a pair of photons to an electron-positron pair and back to a pair of photons.

* It is interesting to compare Wolfram's model of relativistic time dilation (pp. 523-524) with the klystron models we discuss in **OP**. One might also compare his automaton models of elementary particles (pp. 525-530) with the **OP** models built from decimals and with the self-regenerating dynamic lepto-quark models of **OP**.

In spite of a few minor criticisms and the need to bear with the usual scientific whizkid hubris, I enjoy this book very much. It is an excellent (probably the classic) reference work on cellular automata, and a landmark in the evolution of the New Kind of Science. Wolfram definitely deserves his "genius award." He's doing some really good work.

D.A. White
Taipei, Taiwan, 2003
www.dpedtech.com
dpedtech@dpedtech.com
deltapt@ms19.hinet.net