Wolfram Classes/Language Classes Revisited

Stephen Shucart (triplegem@akita-pu.ac.jp)
Akita Prefectural University, Japan

Introduction

Complexity Science is multidisciplinary, and this makes it difficult for many people to understand. Rather than waste time with going over the basic concepts, I shall include hyperlinks to relevant websites so that those who wish can acquire the background knowledge necessary to understand some of the more esoteric references.

In 2002 Stephen Wolfram published a revolutionary book entitled 'A New Kind of Science'. Wolfram was a mathematical prodigy, who received his Ph.D. from Yale at the age of 20. While doing post-doctoral work at Caltech he decided to investigate Cellular Automata (CA), a form of artificial life. By 1984 he discovered that he could classify the long-term behavior of CA into four distinct types, no matter which local rules he started from. He had to write his mathematics programs for the investigations, and this lead to his retirement from academia to found a software company, Wolfram Research, Inc., and become a multimillionaire. He never abandoned his original research, but instead financed it himself. The result was his magnum opus, 'A New Kind of Science'. The book covers a vast array of subjects, from quantum physics to natural systems - including languages -, to computational evolution, to the ultimate speculation that the entire universe is nothing more than a vast program running cellular automata balanced on the edge of chaos.

In 1998 I wrote a paper for the journal 'CALLing Japan' which used Wolfram's four Universality Classes as a model for the four different ways that CALL classes can be run (Shucart; 1998). That paper, 'Wolfram Classes/Language Classes', was based on Stephen Wolfram's early work with CA. Now that Wolfram's theories have matured, I shall endeavor to revisit that earlier paper and upgrade my conclusions in light of his current research.

I have used Wolfram's four Universality Classes to model emergence as a phase transition between levels within a multidimensional framework. An understanding of the separation of scale is necessary to comprehend the place of Second Language Acquisition (SLA) in the current model. The acquisition is a form of emergence, a phenomenon that seems to have a fractal presence in our space-time continuum. Painted in broad strokes, it stretches from the Big Bang instant when Planck-length superstrings began to sing out an existence in 11-dimensional Calabi-Yau shapes (Green, 1999), through the coalescence of hydrogen and helium, the flash of nuclear fusion, the formation of solar systems, and the jump from inorganic to organic. Narrowing the focus to our earthly biosphere, life emerged and adapted under the random variables of gravity, atmospheric composition, and catastrophic collisions with cosmic debris to the tune of epochal evolution (punctuated equilibrium). Mammalian, primate then hominid minds coevolved with social systems through the Peircian levels of Iconic, Indexical, and Symbolic consciousness until reaching today's post-modern level of language and culture (Deacon, 1992; Mithen, 1995; Noble and Davidson, 1996).

Language is a Complex Adaptive System (CAS), as is Life, Consciousness, Culture, and the Tokyo Stock Market. Of course, such things are beyond the modest scope of this paper. What I propose is to use insights from Complexity Science in such fields as evolutionary biology, artificial life, and computer science to present a model of second language emergence within the group dynamics of a classroom setting.

The early promise of Complexity Theory never quite managed to revolutionize the mainstream of modern science. Wolfram explains it thus:

> 'Watching the history of the field of complexity theory has made it particularly clear to me that without a major new intellectual structure complexity cannot realistically be studied in a meaningful scientific way. But it is now just such a structure that I believe I have finally been able to set up in this book,' (Wolfram, 2002, p.863)

John von Neumann, one of the fathers of modern computing, wanted to design a self-replicating machine. With the help of the mathematician Stanislaw Ulam, he designed the first Cellular Automata. CA are the simplest form of Artificial Life (Alife). They are a collection of cells performing the computation in unison based on simple, local rules. The steps are discrete, but each step depends not just on the state of the individual cell, but also its neighbors. They evolve (Coveney and Highfield, 1995).

Wolfram investigated the 256 different, simple rules for two-colored CA. Each of these rules generated cellular automata that eventually fell into a basin of attraction and settled into one of four universality classes (Wolfram, 1984). A basin of attraction is like a valley with a lake at the bottom. When it rains, no matter where a drop falls, it will eventually find its way to the lake at the bottom. In this case, the lake symbolizes some form of the attractor.

Wolfram's latest research adds a second variable to the insight that 256 simple rules generate CA that evolve into one of four basic classes. That variable is 'initial conditions'. The infamous 'Butterfly Effect' 'Does the Flap of a Butterfly's Wings in Brazil Set Off a Tornado in Texas?' (Lorenz, 1979) - picturesquely describes that sensitivity to initial conditions that is so intrinsic to Chaos Theory. The classes denote increasing complexity, though each class contains certain immediate, distinctive features. Wolfram explains this sensitivity to initial conditions:

'These four classes also have other significant distinguishing features—Õheir sensitivity to small changes in initial conditions. In class 1, changes always die out, and the same. The final state is reached regardless of what initial conditions were used. In class 2, changes may persist, but they always remain localized in a small region of the system. In class 3, however, the behavior is quite different. Any change that is made typically spreads at a uniform rate, eventually affecting every part of the system. In class 4, changes can also spread, but only in a sporadic way.' (Wolfram, 2002, pp. 251-2)

Class 1: Wolfram states: 'The behavior is very simple, and almost all initial conditions lead to the same uniform, final state.' (Wolfram, 2002, p.231) The Class 1 attractor is a linear, Fixed-Point attractor - like a ball bearing rolling around in a funnel and eventually dropping out the bottom.

Class 2: ' In class 2, there are many different possible final states, but all of them consist just of a certain set of simple structures that either remain the same forever or repeat every few steps.' (Wolfram, 2002, p. 235) The attractor for this state is a linear,

Limit-Cycle attractor. It resembles a ball bearing rolling endlessly around a grooved pathway, or a child's racing car rushing round and round the fixed lanes of a racetrack.

Class 3: 'In class 3, the behavior is more complicated, and seems in many respects random.' (Wolfram; 2002, p.235) Class 3 behavior is nonlinear. The pattern never repeats, yet still evolves by the rules. Deterministic Chaos, the Strange Attractor, is the symbol for this basin.

Class 4: 'Class 4 involves a mixture of order and randomness; localized structures are produced which on their own are fairly simple, but those structures move around and interact with each other in very complicated ways.' (Wolfram; 2002, p. 235) Complex patterns grow and contract in cascades of Chaos connecting islands of Order. This is the phase transition between Order and Chaos, the so-called 'Edge of Chaos' where life, learning, and evolution all take place. One significant feature of class 4 systems is that 'In each case, the initial conditions are completely random, but, after just a few steps, the systems organize themselves to the point where definite structures become visible' (Wolfram, 2002, p. 281) Self-organization is one of the key components of emergence in any Complex Adaptive System. Thus gaining an understanding of Wolfram Class 4 is one of the main goals of Complexity Science.

In 'A New Kind of Science' Wolfram also points out that how each class responds to the differences in the initial conditions is extremely significant in that it reflects how each class of systems handles information: In class 1, information about initial conditions is always rapidly forgotten for whatever the initial conditions were, the system quickly evolves to a single final state that shows no trace of them. In class 2, some information about initial conditions is retained. In the final configuration of structures, but this information always remains completely localized, and is never in any way communicated from one part of the system to another. A characteristic of class 3 systems is that they show long-range communication of information so that any change made anywhere in the system will almost always eventually be communicated even to the most distant parts of the system. Class 4 systems are once again somewhere intermediate between class 2 and class 3. Long-range communication of information is in principle possible. But it does not always occur for a particular change is only communicated to other parts of the system if it happens to affect one of the localized structures that move across the system.' Wolfram, 2002, p. 252

Wolfram Classes are the simplest frameworks to model general classroom behavior. The 'initial conditions' we shall focus on are the language and methodology used for communication in the classroom. Of course, many other variables could be included under the terminology of 'Initial Conditions'; the student's level of English, the conditions of the classroom, the competence of the teacher, the time of year, the weather, etc. But, for the sake of simplicity, I will allow these other variables to cancel each other out. In real life, elements of all four classes can be found in the same teaching environment, but, for means of clarity as well as levity, I shall exaggerate the overall effects.

Wolfram Class 1 'Death in the Afternoon'

Class 1 behavior swiftly settles to a fixed-point attractor; equilibrium and entropy. New information, whether in the form of the teacher's well thought out communicative exercise or a boring grammar lecture, is quickly forgotten. This could easily be envisioned as a

sarin gas attack leaving the students slumped over their textbooks or lying on the floor in various attitudes of death. A CALL class where students are electrocuted while inserting the CD-ROM can have the same effect. Less extreme examples would include a lecture so boring that the students fall asleep, low-crawl out the back door, or students in various states of catatonia from alcohol or mind-numbing drugs. Daydreaming to the point where all class content flows in one ear and out the other with zero retention is also a definite indication of Class 1 behavior. At its best, the language class is narrow-focused on memorizing an obscure grammar point or engaged in a Grammar-Translation exercise with only one correct answer.

Wolfram Class 2 'The Language Lab'

Class 2 behavior is marked by the limit-cycle attractor. The new information remains completely localized, never transmitted from one part of the class to the other. There is no context for the students to process the information holistically. The activities are linear and very cyclic. The Audio-lingual language lab of the 1950s and '60s seems to be the best representative of this teaching style. The students merely listen and repeat patterns over and over until they are memorized. Another example is the Japanese 'Juku' or Cram School where students acquire the ability to pass rigorous College Entrance Exam multiple-choice grammar tests, yet cannot hold a simple conversation.

The fossilization familiar from Interlanguage studies would also fall into Class 2. The student has reached a level of fluency sufficient for his or her needs and becomes stuck. The student can handle relatively easy class material and lacks the incentive to push harder (Ellis, 1985). A CALL class in which the computer is used as an electronic blackboard to write the answers to textbook activities, or to post listening transcripts has a limit-cycle attractor.

Wolfram Class 3 'The Butterfly Knife Effect'

Class 3 behavior is nonlinear. The strange attractor shows wild results from small changes to the initial settings. The class is Chaos confined. New information is communicated rapidly to the entire class, but no one seems to care. A simple activity quickly degenerates into students gossiping in their first languages, answering calls on their cell phones, or butterfly knife fights at the back of the class. The noise level will usually increase as students shout and wander in from other classes, or refuse to remain seated. Discipline is nonexistent. A CALL class finds students reading about Pop idols on L1 websites, playing solitaire, downloading hardcore pornography, or participating in an online RPG or a dating chat room. A peanut butter sandwich in the CD-ROM Slot would not be unusual.

Wolfram Class 4 'Life on the Edge'

Class 4 is balanced on the Edge of Chaos. The attractor is Self-Organized Criticality. Classroom language is at the optimal i+1 Level proposed by Krashen (Krashen, 1978),

and the interactions are within Vygotsky's 'Zone of Proximal Development (ZPD)'. He states:

> 'We propose that an essential feature of learning is that it creates the zone of proximal development; that is, learning awakens a variety of internal development processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers. Once these processes are internalized, they become part of the child's independent developmental achievement.' (Vygotsky, 1978)

A classroom in Wolfram Class 4 could be organized into many pairs or small groups engaged in meaningful communication to complete a task with a specific goal. The language should be structured, yet remain open enough to include a random element to trigger the emergence of fluidity or creativity. A CALL example would have two students sharing a computer and interacting to solve multimedia problems, engaging in critical thinking on a research project, or single students connected on a local network or through video conferencing software to experience actual conversations. As computers become even more powerful, the potential for full immersion experiences via virtual reality could give a Matrix-like sensibility to interactive classes with students from around the world meeting as Avatars in a consensual universe designed specifically to foster language emergence.

Conclusion

Wolfram's 'A New Kind of Science' is a massive tome whose breadth of scope is beyond the narrow confines of this present paper. By focusing on these four universality classes I hope that teachers will gain some insight into how language classes evolve and answer the question of why some lessons will fail miserably and others seem to have an almost magical effect on acquisition.

In the centuries before microscopes and germ theory, local shamans and medicine men would treat illness and injury with natural herbs and healing rituals. Many of those herbs now form the basis for modern pharmaceuticals. The shamans didn't know why the herbs worked, they just did. In many ways, we are the local shamans of language teaching. There are many theories as to why a methodology works, some correct, and some mere fantasy. The important point is that they do work. Modern chemistry has allowed scientists to extract active ingredients to combine and create more effective medicine. This is the place I see for Complexity Science, extracting the patterns that are most effective at allowing the student's minds to self-organize and emerge on the next level of communicative competence. In my opinion, Wolfram's four universality classes offer one of the best templates with which to judge the efficacy of practical language acquisition in the classroom setting.

References

Coveney, Peter, and Highfield, Roger. (1995). *Frontiers of complexity: The search for order in a chaotic world*. Ballantine Books: New York.

Deacon, T. (1992). *The symbolic species*. New York: W.W. Norton.

Ellis, R. (1985). *Understanding second language acquisition*. OUP: Oxford.

Gleick, J. (1987). *Chaos: Making a new science*. Penguin: New York

Green, B. (1999). *The elegant universe*. New York: Vintage

Krashen, Stephen. (1981). *Principles and practice in second language acquisition*. Oxford: Pergamon.

Lorenz, E. (1979). 'Predictability: Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?' Address to the American Association for the Advancement of Science, Washington D.C.

Noble, W., & Davidson, I. (1996). *Human evolution, language, and mind*. Cambridge: CUP.

Mithen, S. (1995). *The prehistory of the mind*. New York: Thames and Hudson

Peirce, C. (1978). Collected papers. Vol. II. Elements of logic. Cambridge, Mass: Belknap.

Shucart, Stephen. (1998). Wolfram classes/language classes, *CALLing Japan*, 7(2). http://jaltcall.org/cjo/5_98/cjo5_98.htm

Vygotsky, L. S. (1978). *Mind in society*, Harvard University Press: Cambridge, Mass.

Waldrop, M. Mitchell, (1992). *Complexity: The emerging science at the edge of order and chaos*. Simon & Schuster: New York.

Wolfram, S. (2002). *A new kind of science*. Wolfram Media Inc.: Illinois.

Wolfram, S. (1984). 'Cellular Automata as Models of Complexity' *Nature*, 311, 419.