LANGUAGE EMERGENCE

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INTRODUCTION

Linguistics, like most sciences, has traditionally started at the top, viewing language as a complex machine, and has worked its way down analyzing a hierarchy of component parts. Analysis means ‘ the separation of an intellectual or substantial whole into constituents for individual study’ . (Langton, 1996). But there's more to language than mere mechanics, there is also dynamics. The principles of dynamical self-organization are rarely touched upon by traditional analytical methods, and the reason for this is simple; self-organization is a fundamentally non-linear phenomenon. Non-linearity depends on the interactions between parts, and this non-linearity disappears when the parts are analyzed in isolation from one another.

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. I have divided this paper into two main sections. In Part One, 'Wolfram Classes／Language Classes', I shall apply work done by the mathematician Stephen Wolfram on the four universality classes of cellular automata and research in the field of Artificial Life by Christopher Langton to present the basic framework of classroom dynamics. In Part Two, 'Chasing the Red Queen', I shall use the research of Dr. Stuart Kauffman on co-evolving fitness landscapes and auto-catalytic sets plus the work of Physicist Per Bak on Self-organizing Criticality to expand on the earlier framework.

Diane Larsen-Freeman, in her groundbreaking 1997 paper for the journal *Applied Linguistics*, 'Chaos／Complexity Science and Second Language Acquisition', listed ten key terms which apply to Complex Systems. Since these features will be mentioned throughout this paper, I think it best to define them at the outset. I will present her original description, and, sometimes, add a comment of my own.

1) **Dynamic** - Constantly changing over time.
2) **Complex** - Many components or agents whose behavior emerges from the interactions between them.
3) **Nonlinear** - A system in which the effect is disproportionate to the cause.
4) **Chaotic** - Here I take exception to her definition. She states: "Chaos refers simply to the period of complete randomness that complex nonlinear systems enter into irregularly and unpredictably." This is the layman's idea of 'Chaos'.

Better is Kumai's (1999) definition: "seemingly random, yet with deep structural patterns."

5) **Unpredictable** - Outcomes cannot be determined in advance. To me this is merely a feature of nonlinearity.
6) **Sensitive to Initial Conditions** - The famous 'Butterfly Effect'. "Does the Flap of a Butterfly's Wings in Brazil Set Off a Tornado in Texas?"(Lorenz, 1979). Again, this is a feature of a Nonlinear Strange (Chaotic) Attractor.
7) **Open** - An open system allows information and/or energy to flow in from the outside. This energy is necessary for the emergence of greater complexity. On the contrary, a closed system is subject to the 2nd Law of Thermodynamics, i.e. Entropy.
8) **Self-Organizing** - Structure or patterns form on their own. Or, as Kauffman (1996) puts it: 'Order for Free.'
9) **Feedback Sensitive** - Feedback acts as a cybernetic governor to regulate the rate of change.
10) **Adaptive** - The agents do not simply respond passively to events, but actively learn from environmental changes and responds to take the maximum advantage. (Larsen-Freeman, 1997)

I WOLFRAM CLASSES/LANGUAGE CLASSES

The concept of 'Phase Space' is one of the most powerful inventions of modern science. It is a way to turn numbers into pictures, and give a flexible roadmap of all the possibilities of a dynamic system. Before the invention of powerful computers physicists could only model linear differential equations in phase space. There are only two attractors that can be pictured with linear dynamics, the Fixed-Point and Limit-Cycle attractors. On a two-dimensional phase space picture, a Fixed-Point Attractor is just that. After a short time the system settles into a straight line. This is equilibrium, the 2nd law of thermodynamics, or entropy. A Limit-Cycle Attractor looks like a wavy line repeating itself. It can have two, three or more waves, but it always repeats.

A Strange or Chaotic Attractor is created by solving a nonlinear differential equation. It is both deterministic and dynamic; a fractal. Fractals, a term coined in 1975 by Benoit Mandelbrot, describe a seeming impossibility - a fractional dimension. It is an infinitely changing pattern, never repeating, self-similar across scales. When it is pictured in two dimensions it merely appears as a ragged line, just random noise. At least three variables are needed before the pattern takes on its distinctive shape ; owl's eyes, or the wings of a butterfly. It is infinite change confined within the finite box of phase space (Gleick, 1987) .

Stephen Wolfram was a mathematical prodigy, receiving his Ph.D. from Yale at the age of 20. While doing post-doctoral work at Caltech he decided to investigate Cellular Automata (CA). 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.

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 computation in unison based on simple, local rules. The steps are discrete, but each step depends not just on the state of the indivi dual cell, but also on its neighbors. They actually evolve over time (Coveney and Highfield, 1995).

After an exhaustive study Wolfram found that all cellular automata would eventually fall into a basin of attraction and settle 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 attractor.

Wolfram Class I: CA which fall into this class of behavior either disappear over time, or become fixed. They reach a static, homogeneous state. The Class I attractor is a linear, Fixed-Point attractor - like a ball bearing rolling around in a funnel and eventually dropping out the bottom.

Wolfram Class II: In this class of CA the pattern will evolve to a fixed, finite size, and form orderly structures that will repeat indefinitely. 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.

Wolfram Class III: Class III behavior is nonlinear. The pattern never repeats, yet still evolves by the rules. Deterministic Chaos, the Strange Attractor, is the symbol for this basin.

Wolfram Class IV: 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. Understanding Wolfram Class IV is one of the main goals of Complexity Science.

In 1984 Christopher Langton started work on his Ph.D. under the direction of Dr. John Holland. The subject he chose to investigate was the Wolfram Class IV behavior of cellular automata. Before he completed his work, he had virtually single-handedly founded the field of Artificial Life, and pushed the image of "The Edge of Chaos" to the forefront of Complexity Science.

Wolfram Class IV behavior is a phase transition. There are two types of phase transitions first-order and second-order. In a first-order phase transition the jump is sharp and precise. The molecules make an either/or decision; Water or Ice; Order or Chaos, it's the phase transition we are most familiar with. A second order phase transition is much rarer, but it is the real life embodiment of Wolfram's Class IV CA model. In Alan Guth's Inflationary Model of the early universe a Higgs Field undergoes a second order phase transition from the symmetry of the Big Bang singularity to the broken symmetry of our current universe (Guth,1989). In a second order phase transition islands of order float on a sea of fluid that gradually changes to a continent oflatticework solid dotted with lakes of fluid. Order and Chaos do a complex dance with intertwining submicroscopic arms and fractal filaments.

Langton realized that phase transitions, complexity and computation were all linked. Wolfram Class IV CA were universal computers. Class II CA were stable enough to store information, but there was no way to transmit it. Class III CA were too chaotic and signals would get lost in the noise. Only a computer at Class IV was stable enough to store information and fluid enough to transmit it. Langton said:

> "Life is based on its ability to process information. It stores information. It maps sensory information. And it makes some complex transformations on that information to produce action." (Waldrop, 1992, p.232)

Wolfram Classes are the simplest framework to model general classroom behavior. In real life, elements of all four classes can be found in the same teaching environment, but, for means of clarity, I shall exaggerate the overall effects.

Wolfram Class I - 'Death in the Afternoon':

Wolfram Class I behavior swiftly settles to a fixed-point attractor; equilibrium and entropy. 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. Day dreaming 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 I 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 II - 'The Language Lab':

Wolfram Class II behavior is marked by the limit-cycle attractor. The activities are linear in nature and very cyclic. The Audio-lingual language lab of the 1950's and 60's 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 II. The student has reached a level of fluency sufficient for his or her needs and becomes stuck. The student can handle the 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 has a Class II attractor.

Wolfram Class III - 'The Butterfly Knife Effect':

Class III behavior is nonlinear. The strange attractor shows wild results from small changes to the initial settings. The class is Chaos confined by the phase space of the classroom. 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 increases, 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 from Nasty Jack's Smut Shack (www. nastyjacks.com) or playing QUAKE III deathmatches. A peanut butter sandwich in the hard drive would not be unusual.

Wolfram Class IV - 'Life on the Edge':

Class IV is balanced at the phase transition on the Edge of Chaos. The attractor is Self-Organized Criticality (See Part Two - Chasing the Red Queen). 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 IV 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 still remain open enough to include an element of fluidity or creativity.

A CALL example would be the Internet Scavenger Hunt, where teams of students cooperate in a race to complete a task sheet provided by the teacher. Through the use of computers, the students use language and critical thinking to organize their goals, and attempt to accumulate the most points within a time limit.

II - CHASING THE RED QUEEN

"It takes all the running you can do to keep in the same place. If you want to get somewhere else, you must run at least twice as fast "

-The Red Queen, in "Through the Looking Glass" by Lewis Carroll.

Dr. Stuart Kauffman is a medical doctor and tenured professor of biology at Dartmouth College, but he spends much of his time in New Mexico, at the Sante Fe Institute, where he devotes his life to the search for the laws of Self-Organization and Complexity. To facilitate his research he has adopted the image of the Fitness Lands cape from the evolutionary biologist Sewell Wright .

Picture a rolling landscape of peaks and valleys encompassing all of the possibilities of phase space. The highest peak symbolizes maximum fitness. Kauffman wanted to move beyond the basics of Langton's CA model of an individual agent evolving on the edge of chaos. He was interested in the behavior of a collection of agents coevolving, which is why he brought the landscape image from predator/prey relationshipsin an ecosystem.

When he set up his N-K model of a fitness landscape (N refers to the fact that each species has N genes, and their fitness depends on K other genes, K being the number of connections) he found that the results of his computer simulations fell into the exact same Wolfram universality classes as Langton's CA. The N-K landscape modeled a single species, but species do not exist in isolation. To model the even more complex interactions of multiple species he used an NKCS Landscape. The C stands for connections, and the S stands for the number of species. When he ran these computer simulations he found that the different species all evolved to one of three different sections of the landscape, i.e. an Ordered Regime, a Chaotic Regime, and/or an Edge of Chaos phase transition (Kauffman, 1996).

The agents in the Ordered Regime reached what Game theory calls Nash Equilibrium, or what biology refers to as an Evolutionary Stable Strategy (ESS). They all reach relatively low peaks and, by cooperating, they all feel no need to improve or climb higher. The basins of attraction are limit-cycle attractors.

The Chaotic Regime is sometimes called the Red Queen, after the character in Carroll's 'Through the Looking Glass'. All of the agents are running as fast as they can just to stay in the same place. The peaks are high and jagged, and the agents are competing so ferociously that none can climb very high before being knocked off. The landscape, itself, is deforming faster than agents can improve their positions. Here the basins of attraction are Strange Attractors.

The Coevolutionary Edge of Chaos is the phase transition between the two. This is the realm of the highest mean fitness, a balance between cooperation and competition. This is the regime of the most successful agents in an ecosystem. What kind of attractor is found at the Edge of Chaos?

Per Bak, a Danish born physicist at Brookhaven National Laboratories, along with his colleagues Chao Tang and Kurt Wiesenfield, came up with a theory called Self-Organized Criticality while studying the condensed-matter physics of charge-density waves. They soon found that that it could also explain such diverse phenomenon as earthquake distribution and the vagaries of city traffic (Bak, 1998).

The now classic image of self-organized criticality is the sandpile model. If you pour a steady stream of sand into a tabletop it will form a higher and higher cone until it reaches its maximum height, adding more sand causes an avalanche. The pile is self-organized in the sense that it reaches the critical angle by itself. Its state is critical in the sense that the grains of sand are barely stable, the addition of even one more random grain will trigger an avalanche. It is impossible to predict the size of the avalanche, perhaps only a few grains will slide down, or perhaps a chainreaction will send a massive cascade of sand showering off the face of the pile. Only one thing is certain, the statistical frequency of the avalanche size follows the mathematical principle known as a power law, i.e. the average frequency is inversely proportional to some power of its size.

When Kauffman met Bak at the Sant Fe Institute a crucial piece of the edge-of-chaos puzzle fell into place. Self-organized criticality turned out to be the missing attractor, the Edge of Chaos Attractor, and the picture became clear. It also provided a scale of measurement. When a system is at the Edge of Chaos, critical state waves of changes emerge, and this emergence invariably follows a power law.

Fitness landscapes are probably the best way to model the complex interactions that occur in a language classroom. Unfortunately the extremely high number of possible variables and the nonlinearity inherent in the system make it almost impossible to extract the empirical data necessary for replicable experiments. A classroom can have students and/or groups of students moving between any of the regimes of the fitness landscape. It is the teacher's job to provide the correct level of input, and encourage the students to climb to their points of maximum fitness.

Students deep in the Ordered Regime could be said to be experiencing fossilization. They are on mutually consistent peaks, but the peaks are in the foothills. The students learn a few simple ways to say something, enough to accomplish basic communication tasks, but they endlessly repeat the same patterns with no creativity. These students are often well behaved and cooperative, but much too passive. They are afraid of making mistakes, thus they never experiment. When the tasks are too easy, and the language patterns have already been internalized the students have low motivation and are content with their language level. They can pass their tests and thus have no incentive to improve.

When students are in the chaotic regime a simple mistake can multiply exponentially, causing more and more confusion. The material being presented is usually too advanced for the students to comprehend. Instead of i+1 level input, it is +10. The assignedtask might be too complex or the rules of a game too difficult to understand. Perhaps the task is open -ended, without a clear goal or finish. Students can never reach the fitness peaks because they keep kicking each other off before they get close. Often the noise-level is high, or the teacher's instructions unclear. The overall fitness of this class is low and the peaks are jagged and massive - a moonscape with cliffs and overhangs that mutate as they climb. Students give up in despair, and discipline becomes aproblem. See the examples cited under Wolfram Class III in part one for some other types of behavior experienced in this regime.

Students in the Ordered Regime need more fluidity, more challenge, and those in the Chaotic Regime need more structure or discipline. In between the two the aggregate fitness has reached maximum. Here the fitness peaks are the highest, the information flow is smooth and fast. Students balance cooperation with competition, both pushing and pulling each other to higher levels of fluency. Self-organization is one of the key images for the Edge of Chaos. This sudden self-organization to a higher energy plateau is called 'emergence'. The input is just a little beyond their comprehension, but they are in Vygotsky's Zone of Proximal Development. The teacher tunes the complexity of the tasks to the students needs, and higher levels of fluency emerge spontaneously. Activities are both interesting and fun. This causes student feedback, creative input and spontaneous conversations.

PART III - CONCLUSION

So what is the meaning of all this? Is Complexity Science the 'Magic Methodology' which will transform teaching? Unfortunately, I think not. At best Complexity offers a new framework to view the knowledge that we already have. An activity that works for one teacher or class often falls flat under different circumstances. Complexity

Science is a way to let teachers view classroom dynamics from a higher perspective and analyze why a specific activity works. The main point to remember is that, based on long experience, most teachers already know what works best for their teaching styles and individual classes. Complexity, though, might help us to understand why, and thus help us to design new and improved activities along the same pattern.

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 the active ingredients to combine and create more effective medicine. This is the place I see for Complexity Science, extracting the patterns which are most effective at allowing the students to self-organized their minds to the edge of criticality, then over that edge in a cascade of creativity, to emerge at a higher level of fluency.

Modern technologies of Corpus Linguistics, computer labs, CALL and the Internet are rapidly deforming the fitness landscape of language teaching, but I don't reallysee teachers becoming extinct. Technology should only replace the gruntwork of repetition, and add incentive and student motivation. It's still up to the teacher to tune the landscape and find the lever points in the CAS so as to provide the maximum opportunity for language emergence. Complexity Science isn't the Final Answer, but, who knows, perhaps it describes one of the hidden laws of the universe.

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