Language Emergence in a Terraced Labyrinth

Stephen SHUCART

I - INTRODUCTION

Language is an example of a non-linear, stochastic, dynamical system. Non-linear because the operation of the whole cannot be predicted by a detailed examination of the individual parts. Stochastic because new, unpredictable combinations of words, sentences, and discourse are constantly being generated. Language is a dynamical system because it changes and adapts as it evolves over time.

Complexity is a new science, in part because the computer is the chief tool used in its exploration. Applied Linguistics is but one of the many sciences being rescrutinized with this cross-disciplinary technique. Diane Larsen-Freeman's groundbreaking 1997 a rticle in the journal *Applied Linguistics* was one of the first to advocate this approach.

Larsen-Freeman says:

> ...to call attention to the similarities among
> complex non-linear systems occurring in nature
> and language and language acquisition. It is my
> hope that learning about the dynamics of complex
> non-linear systems will discourage reductionist
> explanations in matters of concern to second
> language acquisition researchers.
> (Larsen-Freeman, 1997, p.142)

Second language acquisition has been modelled with two distinct frameworks taken from Complexity science. The first is best typified by the computer scientist John Holland's model of emergence in a complex adaptive system (CAS). The second framework is taken from Evolutionary Biology, and can be modelled by Dr. Stuart Kauffman's Fitness Landscapes. This paper proposes a synthesis of the two, using the work of James Crutchfield and Erik van Ninwegan on Evolutionary Computation. They developed the Terraced Labyrinth function to explain epochal evolution in both biology and computation. Part II will provide a brief introduction to language emergence in Holland's complex adaptive system. Part III will present language emergence modelled on Kauffman's fitness landscape, and Part IV will merge the two models using the Terraced Labyrinth framework.

II - COMPLEX ADAPTIVE SYSTEMS

When an interconnected network of agents reaches a state of self-organised critically a random event triggers a cascade of novelty, and a higher level of complexity suddenly emerges. The change from water to ice is a physical example of this form a sudden phase transition. The sudden boom or bust of an economic market is another example.

In 1959 John Holland was awarded the first American Ph.D. in Computer Science, and he is the originator of the genetic algorithm. Most recently he has been working on the question of Emergence in Complex Adaptive Systems (CAS). He is attempting to find the answer by breaking the system into its basic constituents. So far he has isolated seven basics, three mechanisms and four proprieties, common to all CAS. It is important to understand that he doesn't see these seven as absolutes, other possibilities are a matter of context pertaining to the specific CAS being studied. Though hemaintains that all of the other 'basics' can be derived from his seven with the appropriate combination. He organizes them in such a way as to emphasize their interrelations (Holland, 1995).

The Nobel Laureate Murray Gell-Mann approaches CAS from the viewpoint of information and how it reaches the system in the form of data. He focuses on sorting the patterns into schema, then comparing the schema with real-world data and using feedback on the viability of schema in predictions among competing variants. This viewpoint is one of the alternative combinations covered by Holland's seven basics. One interesting point Gell-Mann makes, though, is the role of deterministic Chaos. He regards Chaos as a mechanism that can amplify the indeterminacy inherent in quantum mechanics to the macroscopic level (Gell-Mann, 1994).

Professor Jean Aitchison, of Oxford, makes some interesting observations in her book on language evolution which I think is quite relevant in contrasting the Fitness landscape model and the CAS model of language. She states that 'components within the language system . . . interacted with usage of the system in a complex way." (Aitchison, 1996;p.215) She points to the fuzziness of human concepts as a prerequisite for leaps of restructuring. This sounds awfully close to 'Random Walks on a fitness landscape' which is the mechanism for moving between varying peaks in different regimes. If we consider a CAS to describe the evolving structure of language, and the Fitness Landscape to model language processing, then we can envision the dichotomy betweenthe two frameworks. A dicotomy resolved by the Terraced Labyrinth.

Holland ordered his seven basics to emphasize their interrelationships, but to understand their use in language I think that they should be grouped first into mechanisms, then the properties. Here's how I see it:

MECHANISMS

TAGGING: Tags form the boundaries of a CAS and allow for aggregation. They break symmetries and enable us to observe and act on properties previously hidden by the symmetries. Holland gives the image of a pool table full of white cue balls. It's virtually impossible to track the actual cue ball in such a situation, but if you tag it with a red stripe it's easy to follow. This facilitates selective interaction, allowing agents to select among agents or objects that would otherwise be indistinguishable.

At a deep level, tagging could be setting the language typologies, i.e. SVO rather than SOV, and breaking the symmetry of UG. Communication becomes possible and linguistic separation occurs. Tagging appears to be more syntactic than semantic in nature. In a classroom situation this could be equated with a 'Focus on Form', where a teacher 'tags' grammatical forms so that the students can be more aware of them within the communicative task.

BUILDING BLOCKS: These are the nuts and bolts of language: The sounds; words; parts of speech and grammar; the subjects, verbs and objects; nouns and articles, etc. Building blocks generate schema, and these are the components that change during hypothesis testing.

SCHEMA: Schema are the archetypal scripts of communicative interactions: restaurant language; hotel language; the giving directions scenario; etc. (Schank and Abelson, 1977). These are most often models based on actual experiences in the Real World. Schema allow for prediction and anticipation. Learning can often come from 'anticipation failure' and hypothesis testing (Schank, 1988). Gell-Mann says:

> "The process of learning grammar also demonstrates the other features of a complex adaptive system in operation. A schema is subject to variation, and the different variants are tried out in the real world. In order to try them out, it is necessaryto fill in details, such as the ones that were thrown away in making the schema. That makes sense, since in the real world the same kind of data stream is encountered again as that from which the schema was abstracted in the first place. Finally, what happens in the real world influences which variants of the schema survive."   (Gell-Mann, 1994, p.54)

PROPERTIES

AGGREGATION: This is the hierarchical or nested-network nature of all CAS. In language this would be the progression from sound to word to sentence to paragraph

to discourse and/or internal speech to monologue to dialogue to group interactions to speech community to all L1 speaker to the global community of L1 and L2 speakers of a language. Perhaps even Interlanguage could qualify as the emergence of higher and higher level aggregates the steps on the path to fluency.

NONLINEARITY: This resonates with the very deepest recesses of language. Small changes in the jump from UG to parameter setting trigger a Butterfly Effect, or an avalanche of switch settings. Chomsky comments:

> "Change in a single parameter may have complex effects,
> with proliferating consequences." And " A few changes in
> parameters yield typologically different languages."
>   (Chomsky, 1981;p.6 and Chomsky, 1986;p.152)

Small changes at the beginning of the semester or class can trigger unpredictable changes in the results. The nonlinearity of language emergence is a hallmark of a class climbing towards the peaks of maximum fluency, and it is intrinsic to all of the models present here.

FLOWS: A network of nodes and connections. The nodes being the agents or students, and the connections are the messages and ideas flowing between students or between the teacher and students. The teacher controls the flow in a classroom and adjusts it for maximum information; the Krashenite i+1. Tags define the networks by delineating the critical interconnections. This could explain the success of 'Focus on Form' exercises to raise the comprehension level of the input and output. Adaptive processes select for tags that cause communication and against the tags that cause misinformation.

DIVERSITY: The cooperation/competition balance in the classroom/student/consciousness that encourages emergence. Evolution is diversity; a dynamic pattern the standing wave of language. Diversity is the product of progressive adaptation to new situations/expectations/ schema refining. Adaptation equals changes in structurebased on experience. Diversity and adaptation is the reason why a teacher needs to constantly adjust the cooperation/competition balance of his lessons to promote maximum opportunities for greater levels of fluency to emerge.

These seven basics of a complex adaptive system, when applied to the language classroom environment, point out the variables and mechanisms which drive the students across the fitness landscape image from Part II. The goal is to raise the teacher's awareness of the mechanisms of language emergence.

In Complexity Science the term emergence denotes the unpredictable, spontaneous reorganization of the components of a parallel distributed network at a higher level

(Holland, 1998). The meta-agent emerges from the network of agents. This can be seen all around us. A living cell emerges from a network of chemicals; organs emerge from a network of cells; a human being emerges from a network of organs; and society emerges from a network of human beings.

Language and the modern mind emerge from the interplay of a number of networks. In the purely physical realm, brain modules emerge from a network of neurons, consciousness emerges from this network of modules, but what about language. Professor Merlin Donald (1991) speculates that it was a side effect from transition of different forms of memory that gave rise to language and the modern mind. He divided memory into several different styles, each one emerging from the previous. Episodic memory is common in higher animals, apes and early man. Mimetic memory separated Homo Erectus from the less complex earlier forms, and primitive forms of Homo Sapiens evolved a mythic memory. Proto-Language began in the Mimetic realm, but didn't take on its final shape until the emergence of longer blocks of coherent discourse in the form of myth (Donald, 1991).

III - FITNESS LANDSCAPES

The evolutionary biologist Sewell Wright introduced the Fitness landscape model of co-evolutionary adaptation to describe the relationships of various species evolving simultaneously in the same environment. Dr. Stuart Kauffman of the Santa Fe Institute adapted the fitness landscape model for his work on complexity science and self-organisation. In their work evolving populations stochastically crawl across a dynamic landscape of peaks and valleys searching for a peak with the highest fitness. The various fitness peaks are associated with the mathematical concept of an attractor. The peaks themselves, if reversed, could be viewed as basins of attraction. When exploring a fitness landscape, it is found that the peaks representing similar attractors group themselves into realms. The limit cycle attractors are those peaks in the Ordered realm. Species in the ordered realm have evolved an Evolutionary Stable Strategy (ESS). Those in the Chaotic, or Red Queen realm are evolving on peaks which are chaotic or strange attractors.

"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.

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 one of the three classes of attractors. 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 foundt hat 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.

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 chain reaction 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.

Fitness landscapes are one of the best ways 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 reductionist 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 contentwith 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 $i+10$. The assigned task 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 a problem.

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. 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. These types of classes almost run them-selves.

IV - THE TERRACED LABYRINTH

The standard model of Darwinian evolution can be explained as gradual change and adaptation via the mechanisms of mutation and natural selection. In 1972 Stephen J. Gould and Nils Eldridge added the concept of punctuated equilibrium to better explain the lack of transitionary forms in the fossil record. Most species show long periods of relative stability, punctuated by a short burst of evolutionary development. Complexity science, especially as it relates to the field of Artificial Life, seems to confirm the existence of punctuated equilibrium in computer simulations. The Terraced Labyrinth

model of epochal evolution provides an explanation for this mechanism.

Exaptation describes a structure that emerges in evolution before the function it now performs. Stephen J. Gould (1991) calls the human brain "the best available case for predominant exaptation". There has been a consistent and identifiable pattern of increase in brain size for the past 3.5 million years. Braincasts from 2 million-year-old hominid fossils show an area corresponding to Broca's Area, one of the sections of the modern brain devoted to language processing. It is my opinion that language and the modern mind co-evolved via the Terraced labyrinth model of epochal evolution.

Crutchfield and Nimwegen (1999) state: "Epochal evolution is dynamical behaviour in which long periods of stasis in an evolving population are punctuated by sudden bursts of change." I believe this to be the case with not only with the physical attributes of hominid evolution, but also the mental evolution of human cognition, and both first and second language acquisition.

The Terraced Labyrinth models each level or 'terrace' as a network of neutral sub-basins connected by portals. A quasi-stationary distribution is maintained via selection and mutation as individual agents randomly diffuse and explore the neutral sub-basins until a portal to a level of higher complexity is found. The population then undergoes an adaptive innovation and emergent behaviour again stabilises on the higher level terrace. I believe that each terrace level can be viewed within the framework of Holland's seven basics of a CAS or modelled as a Kauffman fitness landscape. The innovative structure of the terraced labyrinth explains the emergence of a hierarchy of complexity difficult to envision in the standard models.

In the standard model of a language emergence on a fitness landscape, the agents made random walks round the landscape searching for a peak with the highest fitness. This was to be found on the 'edge of chaos', that area of self-organised criticality between the peaks in the ordered realm and those in the Chaotic realm. Once there, a random event would trigger an avalanche to a peak of higher fitness. The avalanche metaphor of Per Bak, though a good description, still left an unsatisfactory feeling of something lacking in the explanation. If the avalanche could be imagined as the portal to a higher terrace, then the Fitness landscape framework begins to make sense.

The same holds true with the analysis of Holland's CAS. The agents would form a network of nodes and connections, and, when the number of connections hit a critical mass, theh, through the medium of Constrained Generating Procedures (cgp), emergence would ensue. The important reorganisation of the CAS as a level in the Terrace Labyrinth, now shows that the cgp lever point is actually the portal to a higher terace. Thus the Fitness landscape image and the Complex Adaptive System framework are both seen to be descriptions of levels in the Terraced Labyrinth.

V - CONCLUSION

This paper takes the two standard models of language emergence, the Fitness Landscape, and the Complex Adaptive System, and not only shows that they view the same phenomena from differing angles, but that they are parts of a larger framework. With the introduction of the Terraced Labyrinth teachers can now incorporate insights gleaned from both models into a hierarchical whole. Though this present paper only focused on language emergence in a classroom context, I also hope to apply these same techniques to the questions of how the human mind first evolved to the stage were language became a necessary tool, and to the actual process of second language acquisition within the mind of an individual learner.

END

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