Language Networks as Complex Systems

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Abstract

Starting in the late eighties, with a growing discontent with analytical methods in science and the growing power of computers, researchers began to study complex systems such as living organisms, evolution of genes, biological systems, brain neural networks, epidemics, ecology, economy, social networks, etc. In the early nineties, the research gradually spread into the language field. Linguistics began to simulate language networks as complex systems at word, syntactic and semantic levels. This is in contrast to the conventional Chomsky's hierarchy structure and analytical approach. Some researchers even tried to simulate the origin of language, a topic which used to be suspended in European academes a century ago. The numerous researches indicated that language networks are showing some properties of complex systems: scale-free, small world, self-organization and emergence. In this presentation, the author will argue the effects and the implications of choosing language networks as complex systems in language acquisition.

Introduction: Why Complex Systems?

In our daily lives, we have to run many routines for regular errands, such as putting on clothes in the morning, brushing teeth before breakfast, and tying shoe laces prior to leaving the house. If you think much about these routines, you should realize that they are not really the same steps or daily procedures. However, we give them the same labels and treat them the same, although these routines are constantly changing "routines." To survive, we human beings have the tendency to turn a dynamic world into named objects, and assume these terms have been fixed. Otherwise, we cannot move forward at all if we have to wonder from moment to moment which foot has to be extended. Even scientists have to simplify real-world phenomena to construct models, theories or laws. More than one hundred years ago, physicists began to realize the flaws of reductionism and started the topic of statistical physics. Even so, that theory is still based on an analytic method in forms of formulae. A half century ago, the technological progress of computers brought the ability to handle non-linear differential equations in a better way. Researchers began to study complex systems by paying attention to the small or negligible factors which have explosive results due to the non-linear effects. Starting in the late eighties, with a growing discontentment with scientific analytical methods in science and the growing power of computers, researchers began to study complex systems such as living organisms, evolution of genes, biological systems, brain neural networks, epidemics, ecology, economy, social networks, etc. In the early nineties, the research gradually spread into the language field. Simply put, complex system theories are beginning to reflect the real world in a more realistic way.

Topology of Complex Systems

A complex system is made of nodes and links. Nodes are the elements or members of the system, and links are the connections between nodes. Links can be directed or undirected, weighted or unweighted. Based on the structure of nodes and links, one can characterize the system by calculating the average node degree, average path length, and clustering coefficient of the system. The calculation of average node degree can be illustrated by the following diagram:

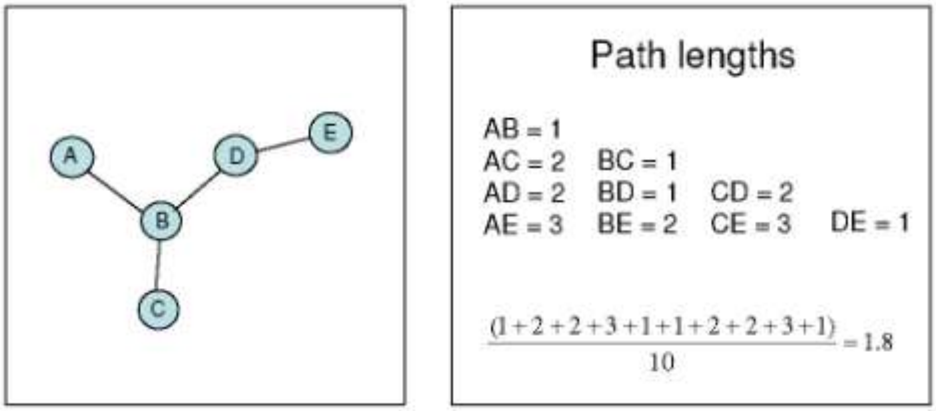

Figure 1. Average node degree[2]

Similarly, the average path length can be figured out as the following:

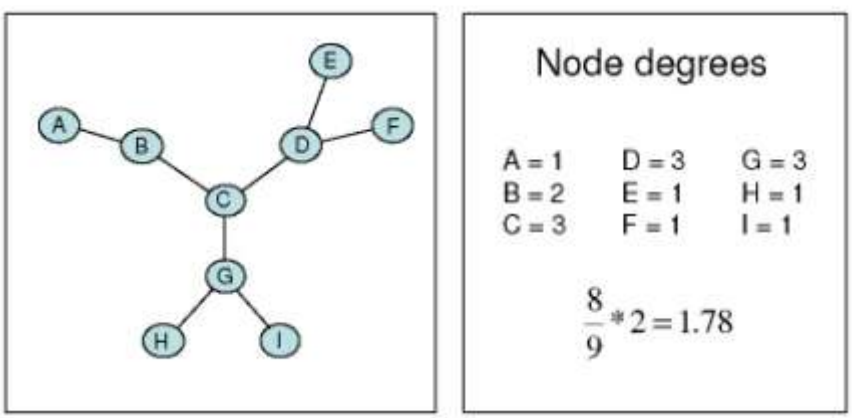

Figure 2 Average path length[2]

The local clustering coefficient of a node *i* is given by the ratio between the number of links among the neighbors of node *i* and the maximum possible number of links among these neighbors. This can be expressed as

$$c_i = \frac{e_i}{[k_i(k_i - 1)]/2}$$

in which c_i is the clustering coefficient, e_i is the number of links, and k_i is the number of nodes[3]. The difference between a strong and weak local clustering system can be shown in the following:

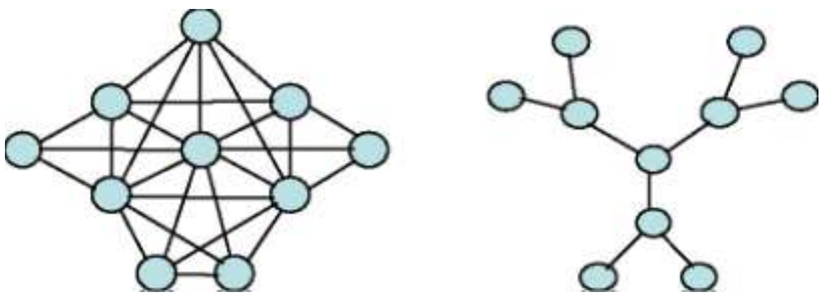

Figure 3 Strong local clustering and weak local clustering[2]

When networks have a short average path length and strong local clustering, they are called small-world systems, in which the neighbors of a given node are more likely to be connected to one another than would be expected through chance alone. Research has also discovered that many real-world systems demonstrate the scale-free characteristic that the system starts with a simple structure and duplicates or iterates the structure to construct a complex system. This can be illustrated by the following artificially constructed depiction:

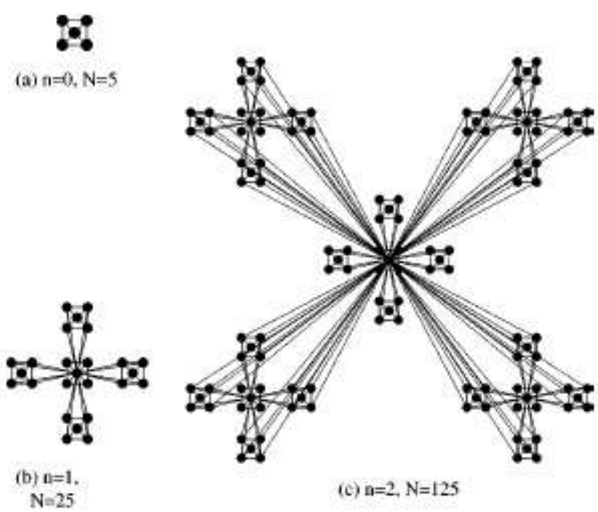

Figure 4 The iterative construction leading to a scale-free network[4]

The scale-free network indicates that the majority of the nodes have a small amount of links, but a few nodes called hubs, can link to most of nodes in the system. The frequency distribution of the system as shown below has a power law relationship:

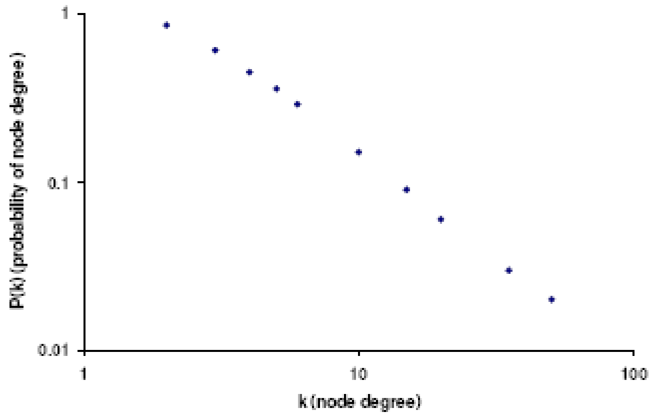

Figure 5 Node degree distribution of hypothetical scale-free network[2]

In summary, a complex system has the following characteristics: (a) its behavior emerges from the interactions of its components and the interaction sometimes is leading to self-organization and the emergence of new behavior; (b) the components change and adapt in response to feedback; (c) it is nonlinear, unpredictable and disproportional to its causal factors; and (d) the emergence is temporary but coherent, coming into existence of new forms through an ongoing process intrinsic to the system.

Although a complex system could be very complex, it has been demonstrated through numerous studies in a variety of areas—from Yeast Protein Interaction to the World Wide Web—that most complex systems have the features of small world and scale-free properties. The next section takes a closer look at language networks.

Research on Language Networks

The rapid growth in complex system study has spread out to diverse areas[5,6]. In this section, the authors focus on the review of research that has been published on language networks. The hierarchical structure of language starts with a single sound at the bottom level, moving up to words by combining many sounds, turning into sentences through linking words, and expanding to paragraphs as sentences are being connected. The corresponding networks to the hierarchical level that have been researched are: vowel-net or consonant-net, semantic networks, syntactic networks, discourse coherence networks, and pragmatics networks.

One hundred and eighty vowels (nodes) are found across 451 languages from the Phonological Segment Inventory Database[7]. In this study, the vowels co-occurring in more than 120 languages are ranked and plotted in the following figure[7]:

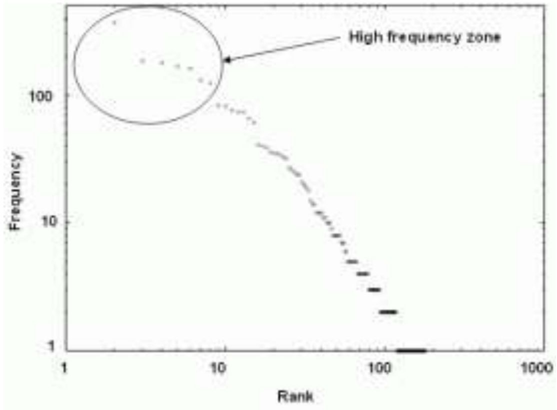

Figure 6 The frequency (y-axis) versus rank (x-axis) curve in log-log scale illustrating the distribution of occurrence of the vowels over the language inventories.

The plot indicates that only a few vowels (hubs) co-occur in the majority of major language families in the world, a property of scale-free networks. The researchers also discovered similar features in consonants networks[8].

The combination of sounds forms the words. Each individual word has no meaning unless it has been linked to the other words or to a word web. The study of this semantic relation has been published by utilizing various Thesauruses[9]. An example[10] of a semantic network is redrawn in the following:

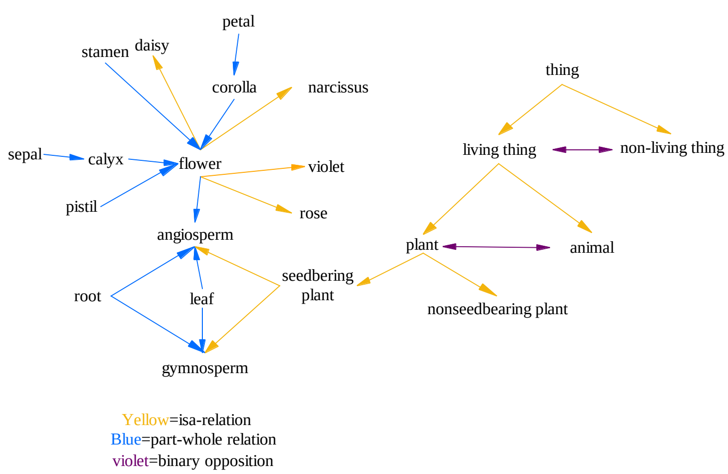

Figure 7 Semantic webs can be defined in different ways. The figure shows a simple network of semantic relations among lexical concepts[11].

The following plot[12] is the distribution of numbers of connections in the word web on a log-log scale. The clustering coefficient C(k) with k for the semantic web indicates its small-world property as shown in the following plot. The web is made by connecting two English words if they are listed as synonyms in the Merriam Webster dictionary. The small-world property can be observed in the plot.

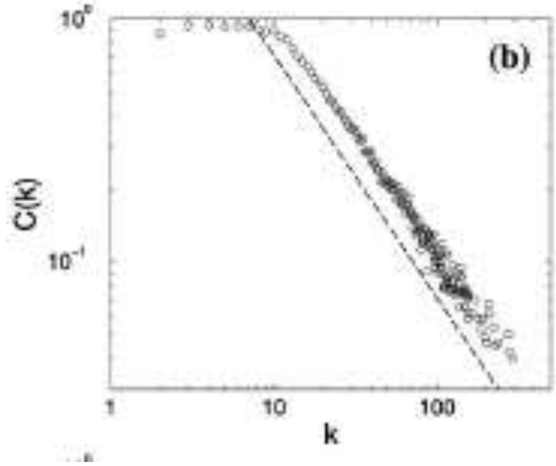

Figure 8. Small-world on semantic network

The scale-free feature of the semantic network can also be illustrated in the following plot[9]:

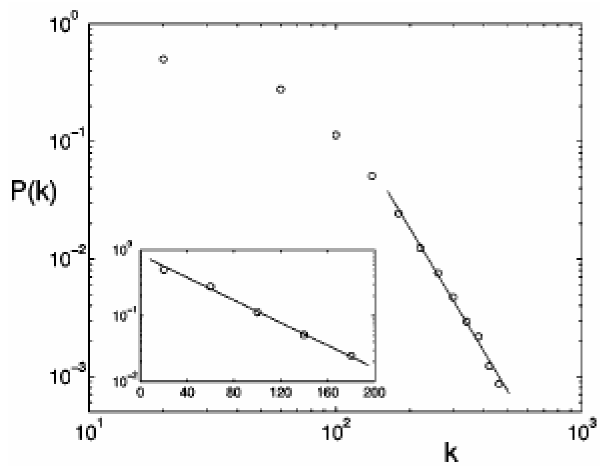

Figure 9. Algebraic scaling behavior of *P(k)* for the conceptual network of the English language. The inset shows the initially exponential decay of *P(k)*.

In Figure 10, the text being shown in part A, two constructed syntactic networks[11] on Virginia Wolf's *A Room of One's Own* are demonstrated in part C and D in the figure. Part C is constructed with the sequence of the sentences. However, part D is constructed with descriptive framework dependency syntax[12] as shown in part B.

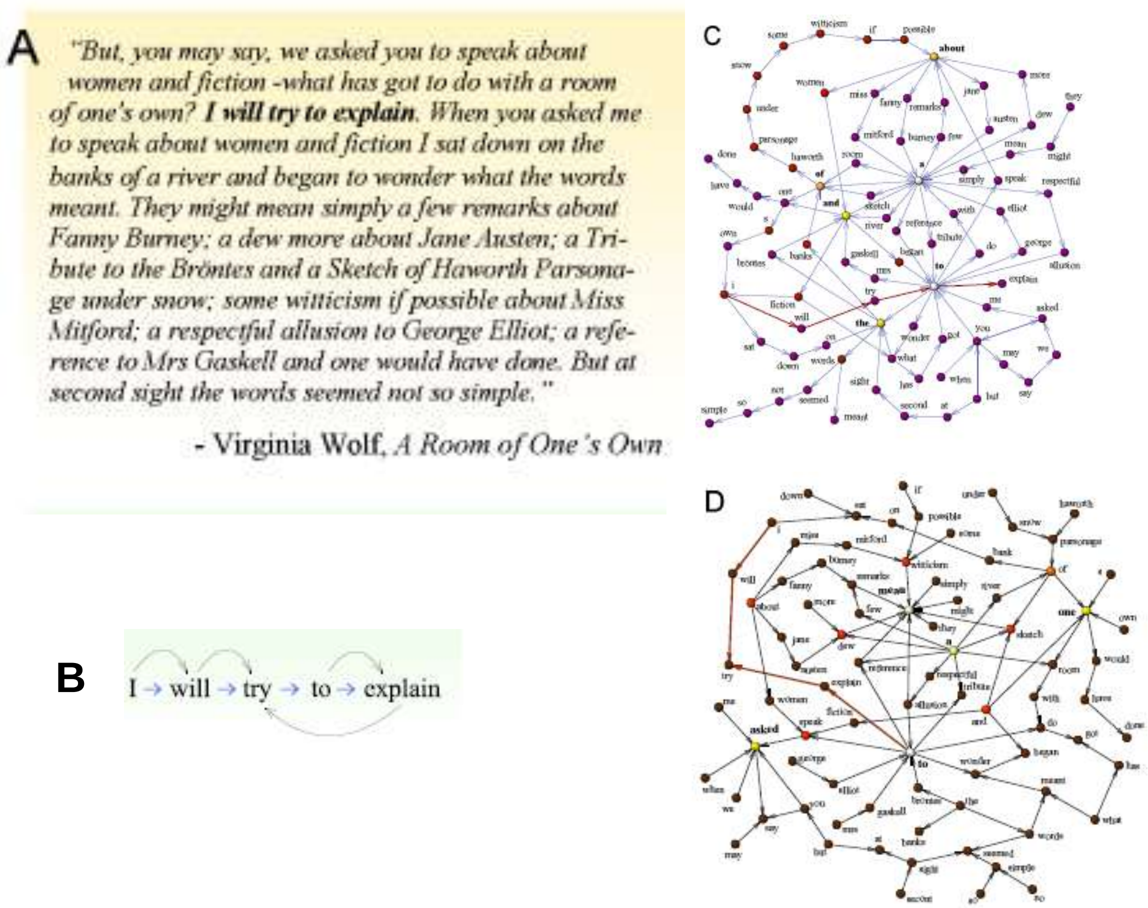

Figure 10. Syntactic networks constructed based on Virginia Wolf's *A Room of One's Own*.

An example of the small-world pattern found in a larger network is shown in Figure 11. The co-ocurrence network is made of a fragment of *Moby Dick*. In this graph, *the, a, of* and *to* are the hubs[11].

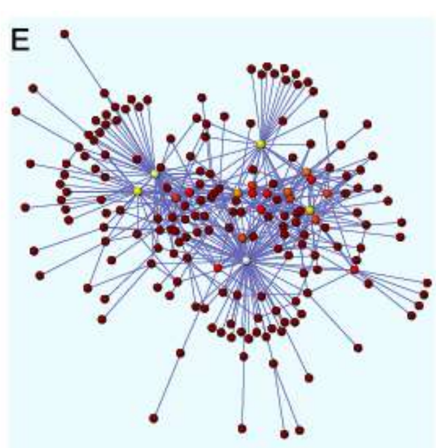

Figure 11. The syntactic network of a fragment of *Moby Dick*[11].

In the meantime, the children's language acquisition process transits from tree-like graphs before 26 months to scale-free syntax graphs at 28 months. These process transits are also investigated and shown in Figure 12[13].

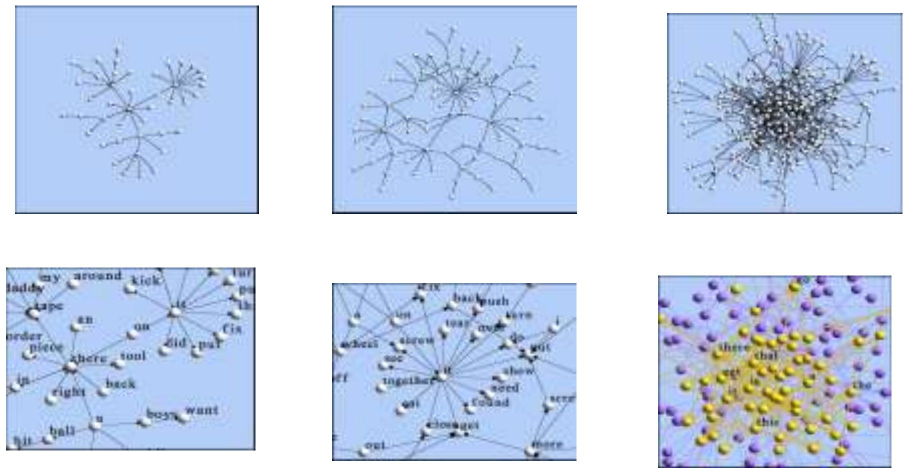

Figure 12. Transitions from tree-like graphs to scale-free syntax graphs through acquisition process[13].

At discourse level, the segments or sentences are considered as nodes and the coherence of the discourse is the focus of the complex system. This can be illustrated in the following example:

S1: The Sunday flight took off from Heathrow Airport at 7:52 PM
S2: and its engine caught fire 10 minutes later,
S3: the Department of Transport said
S4: the pilot told the Central tower he had the engine fire under control.

And the coherence network of these four segments can be depicted as

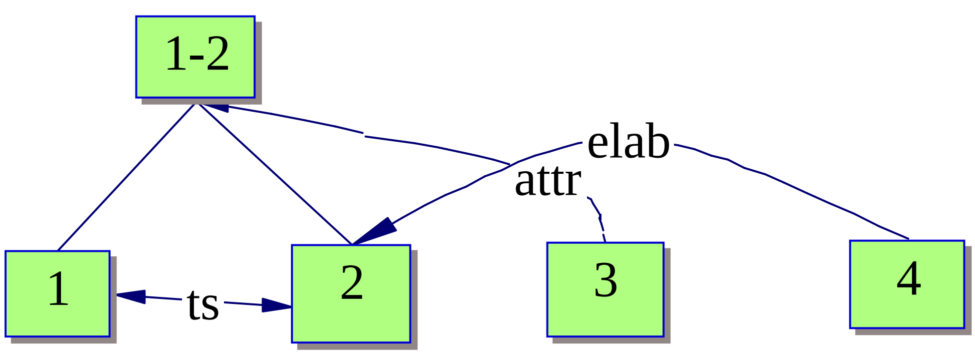

Figure 13 Discourse coherence chart, in which ts=temporal sequence, attr=attribution, source and elab=elaboration[14].

The scale-free character of the discourse coherence can also be illustrated in the following diagram[14]:

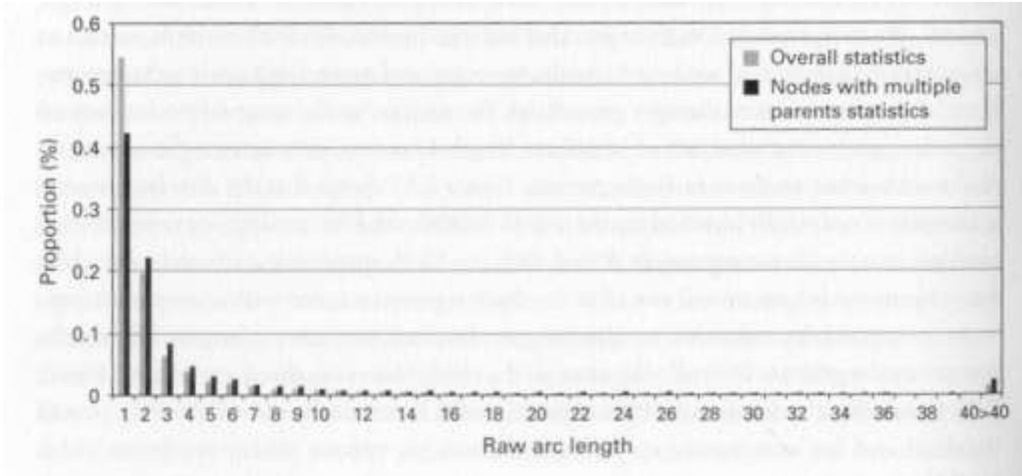

Figure 14 Comparison of arc length distributions. The majority of raw arc length is located within 2 arc lengths prior to normalization on arc raw length.

Implications and Concerns Raised for Language Learning

We can consider that language teaching/learning in the classroom is also a complex system, since language by itself as discussed so far is a complex system. The language teaching/learning system is made of components such as learners, teacher, books, curriculum, languages and environment. Keeping this in mind, the whole teaching/learning can be modeled as a nested complex system since each component in the system is also a complex system by itself. The relations or links among these components/agents to be investigated are interaction between learners and teachers, language resources assembled by teacher and learners, teacher and curriculum, classroom environment and learners/teachers, and learners outside the classroom environment, just to name a few. Furthermore, these interactions are dynamic and fluid moment to moment: the co-adaptation among learners, teachers, and context changes all the time; the change in one could cause change in the other. The range of connection is across levels of human and social organization, as well as across time scales, and any action is tied into the web of connections to multiple systems.

Let's look more specifically at each component of the complex system. Each individual learner is a complex system and has to make his own learning path by considering interference from other languages, age, goals, motivation, social status,[1] etc. Teachers have to raise the awareness of the nature of complexity, be sensitive to individual learners' differences, and monitor the development sequences of individual learners. Teachers have to be aware of not getting all students to move in the same direction at the same time. Teaching does not merely transpose what is in the teacher's head to the students' heads. Also, teachers do not lay out paths for students' learning. The concept of complex systems has generated a paradigm shift on principle of language teaching: teaching "grammaring" (by reasoning), not teaching grammar (by instilling the rules)[15]. The key concept is that language, another component in the complex system, is dynamic, constantly changing, and not a single homogeneous construct to be acquired. Putting this in other aspect, if language ceases to exit in any simple form, how can language teaching/learning be limited to some fixed rules in the textbooks? Language can never be acquired, and it is something that the learners and teachers participate and construct on a daily basis.

Language learning processes have been investigated in literature[1]: learning is a gradual building up process, a period of fluctuation among competing patterns, followed by phase shifting when a critical threshold is crossed; a wider reorganization is triggered or emerged. The learners may work very hard with little success for some time. Then one day, all of sudden, one may reach a critical point and his own system self-organizes in a new way, and this can take the learners to a higher level. The key point is that learning is not just to internalize or memorize a ready-made system.

If language is not a fixed thing to teach and individual learners have their own paths and differences, then the biggest challenge to the teacher is how to assess students' progress in a fair and creditable way, while also insure the college credits transfer and honor academic articulation requirement among colleges. For this, the teacher may have to integrate identifying preferred paths within individual performance with designing individual development sequences or different rubrics for different learners. Tracing individual learners' development sequences or stages is a dramatic task for teachers. This can be witnessed by the abandoning of alternative grading methods at the University of California at Santa Cruz[16].

Conclusion

Complex system theory is a non-linear, dynamic model for real-world phenomena. As demonstrated in this paper, language meets the small-world and scale-free characters of complex systems. Based on this, language teaching and learning have to make a paradigm shift from traditional mechanical language drills or instilling grammar rules into a more dynamic situation application and grammaring teaching by reasoning in the classroom. Language learning, a humanity discipline, has to take advantage of borrowing and benefiting from research study results from complex adaptive system theory, a science discipline. However, the assessment on language learning needs further research in this area.

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