Dynamic Systems Theory Approaches to Second Language Acquisition

WANDER LOWIE

Introduction

Dynamic systems theory (DST) is a theory of change. Starting in the 1960s, the theory has been used extensively in a wide variety of disciplines, from physics to biology and from meteorology to demography. Essentially, DST is an application of mathematics, in which change of complex systems over time is expressed in dynamic equations that describe how these changes take place as a function of time. Each next developmental step (or iteration) is determined by the state of the system at the preceding moment, which leads to unpredictable, nonlinear developmental patterns. DST has provided powerful accounts for the nonlinear, iterative development of natural phenomena. Examples of applications of dynamic systems that show iterative changes over time are found in reaching dynamics (when we reach for a cup on the table, we iteratively adjust the trajectory of our movement) and weather forecasts in unstable atmospheric areas (tomorrow’s weather can be predicted accurately, but long-term predictions are no more than educated guesses due to the large number of dynamic iterations).

Recently, applications of DST have been developed within cognitive science (Thelen & Smith, 1994; Port & van Gelder, 1995) developmental psychology (Van Geert, 1998), and language development (Elman, 1995). Since the late 1990s, the theory has also been applied to second language acquisition (SLA) (Larsen-Freeman, 1997; Herdina & Jessner, 2002; De Bot, Lowie, & Verspoor, 2007). These and many other authors have argued that language can be seen as a complex dynamic system and that language development is a nonlinear, chaotic, and highly individual process that cannot adequately be described from a static point of view. Different authors have used different terminologies for complex dynamic systems. This difference is mainly caused by parallel developments in different areas of research. Within the applications to language development, the terms “complex systems,” “complex adaptive systems” (Ellis & Larsen-Freeman, 2009), and “dynamic systems” (De Bot et al., 2007) refer to similar approaches, although “dynamic systems” is more frequently associated with studies that use mathematical modeling (e.g., Caspi, 2010).

The arguments for considering (second) languages as complex dynamic systems revolve around three crucial characteristics that can suitably be applied to language and language development: the existence of interconnected subsystems; the tendency to self-organization; and the occurrence of nonlinear, chaotic patterns of development. Each of these characteristics will be discussed in some detail below.

Subsystems

An important characteristic of dynamic systems is that they are constituted by numerous embedded subsystems that interact dynamically (Thelen & Smith, 1994). The concept of embedded subsystems is best illustrated by a well-known example of a dynamic system: a flock of birds. The dynamically changing shape of the flock is caused by the movements...
of the individual birds. Each bird in the flock can be seen as one subsystem in an interconnected set of subsystems. Subsystems are nested. Each subsystem can again consist of several nested, or embedded, subsystems. In the bird example, the bird’s circulatory system, its skeletal system, its nervous system, and its digestive system are all subsystems that may again consist of subsystems. Similarly, the flock of birds is again embedded in its larger environment, characterized by a set of atmospheric conditions, such as humidity, wind, and temperature.

The application of subsystems to SLA is strongly associated with the model of the bilingual mind as proposed by Paradis (2004). Taking a neurolinguistic starting point, Paradis assumes the existence of subsystems within the language system, each of which has its own specialization, such as phonology, morphosyntax, and semantics. These subsystems are “isolable . . . and computationally autonomous . . . , have a specific purpose, and function as a component of a larger unit” (Paradis, 2004, p. 119). The nestedness of subsystems is also found in Paradis’s model; within the linguistic subsystems (e.g., phonology, morphosyntax, and semantics), he assumes nested subsystems for each of the languages that a speaker is familiar with.

There is, however, one crucial difference between the way in which subsystems are defined by Paradis and dynamic subsystems. Basing his view on Fodor (1983), Paradis regards subsystems as modules that function only on each other’s input and output, and holds that for each module “the internal functioning . . . is not affected by the internal structure or even the output of another module” (Paradis, 2004, p. 129). In a dynamic view, subsystems are not restricted to modularity, but actively interact with other subsystems. In an influential book on the continuity of human cognition, Spivey argues against the existence of self-contained modules, and maintains that cognition must be seen in terms of the “continuous probabilistic character of mental activity” (2007, p. 21). In this view, subsystems are not closed modules, but sets of related probabilistic computations over time. This means that subsystems in the dynamic sense are open and connected systems and that their internal structure is strongly interdependent on other subsystems. Evidence of the active interaction of subsystems can be found in the interaction between vision and language in Braille reading, expert lipreading, and the McGurk effect (Spivey, 2007). These examples show that cognitive subsystems are not only embedded in but also strongly interact with the physical subsystem, which is why cognitive subsystems are referred to as embodied (see also Lakoff & Johnson, 1999).

In sum, from a DST point of view, the language system can be assumed to consist of embedded subsystems for all levels of language production and perception, such as conceptualization, semantics, syntax, lexicon, phonology, and phonetics (also see Larsen-Freeman, 1997). Contrary to the modular approach, dynamic subsystems must be assumed to be open, interacting, and emergent systems (Spivey, 2007). Additional languages are not stored in different anatomical localizations, but may be considered as embedded functional subsystems in the dynamic sense, possibly nested within the phonological, morphosyntactic, and semantic subsystems, as proposed by Paradis (2004). This means that aspects of one language (e.g., the lexicon or the phonology) may affect those of other languages. This interaction is dynamic, meaning that it varies over time. In addition to the embeddedness of the language system within the cognitive system, the cognitive system itself has been shown to interact dynamically with the physical system of the body.

**Self-Organizing State Space**

A second characteristic of dynamic systems is that the global dynamic patterns of a system appear from the dynamic interaction of its subsystems. This is called “self-organization.”
Self-organization occurs in any natural dynamic system, from cells in a body to the formation of sand dunes, and takes place in the system itself, in dynamic interaction with external influences. For instance, ripples in a sand dune emerge by the formation of sand grains according to the principles within the complex system of ripple formation. Self-organization is a very strong principle; even when the ripples are disturbed by footsteps in the sand, they will reemerge after some time.

In self-organization, the system as a whole is shaped by the interaction of lower-level subsystems. Research in the field of neuroscience shows that the coordinated behavior of the brain is also largely determined by self-organization (Kelso, 1995). The same conclusion is drawn from other findings in cognitive research. For instance, Van Orden, Holden, and Turvey (2003) show that the background noise in behavioral data recorded during reaction time experiments displays patterns of self-organization of purposeful behavior. Self-organization is also a key feature in current cognitive theories about language development. According to Van Geert, it is likely that language acquisition, like other phenomena expressing natural growth and development, is a self-organizational process (Van Geert, 2003, p. 659). Van Geert points out that self-organization can explain the emergence of complex grammar despite the poverty of input for the child acquiring language, and that no innate language learning property is required to account for the increase of language complexity. This position is corroborated by increasing amounts of evidence in favor of an emergentist view of language acquisition. Using computer simulations of connectionist neural networks, several studies of first language acquisition have shown that self-organization can give rise to the emergence of a complex language system (Li, Farkas, & Macwhinney, 2004). Similar positions have been taken for SLA (e.g., Hernandez, Li, & Macwhinney, 2005), and recently Ellis and Larsen-Freeman (2009) have provided additional evidence for the emergence of a second language (L2) system using a variety of measurements.

Due to their complexity as well as their constant fluctuations over time, self-organizing systems cannot be represented in a simple way. The situation in which a system is at one moment in time is its state. Since in dynamic systems many subsystems interact simultaneously, the state of a dynamic system is determined by the state of all of its subsystems. When the development of a subsystem over time is graphically projected, each of the system’s subsystems makes up one of its many developmental dimensions. Since time is a crucial factor in dynamic systems, the description should take it into account that each of these dimensions can change. So the representation of the system describes the phase (in time) of each of the dimensions. The manifold of changing dimensions as a whole is therefore referred to as the multidimensional phase state of the system, which in mathematics is described as vectors in its state space. Each changing subsystem is one dimension in the system’s state space.

Due to its inherent characteristics in relation to its sensitivity to external conditions, a dynamic system may be drawn to a point or path that specifies a particular volume of state space, called an attractor state (Thelen & Smith, 1994; Kelso, 1995). To take a strongly simplified example, the amplitude of a pendulum is determined by its physical characteristics in combination with gravity and friction. Given these characteristics, the pendulum is likely to follow a particular path, which can be seen as an attractor of the pendulum. Similarly, a system may be inclined to move away from certain states, which are referred to as repellor states.

To imagine the physical appearance of a phase state, a comparison is often made with a ball rolling over a surface that has both lumps (repellors) and holes (attractors). The movement of the ball can be seen as the trajectory of the system over time (Thelen & Smith, 1994). Since a complex system contains many dimensions, it can have multiple attractors and multiple repellors. A multitude of attractors and repellors creates “greater potential for any given trajectory to meander quite nonlinearly in its high dimensional state space.”
Not every attractor or repellor is equally strong; the holes can be deep or shallow, and the deeper a hole is, the more stable the attractor is and the more energy is needed to move the ball out of the hole.

Although attractors may cause parts of (sub)systems to be relatively stable, the entire state space can never be stable. Due to activity in some subsystems or changes in their environments, the system can be disturbed (perturbation) and consequently many dimensions of the state space can change, which can lead to a phase shift of the system (Abraham, 2003). From a DST perspective, this is how learning can be defined in terms of self-organization. With learning, “the entire attractor layout changes” (Kelso, 1995, p. 171). This view of learning is corroborated by studies of neural dynamics, showing that learning coincides with a dramatic reorganization of activity in neural populations (Jirsa & Kelso, 2000).

This implies that learning takes place over time, and is strongly dependent on the preceding state of the system. In other words, learning strongly depends on pre-existing knowledge. As Kelso puts it, “Learning, fundamentally, means the modification . . . of pre-existing capabilities,” and it either competes or cooperates with the learner’s existing capabilities (Kelso, 2003, p. 61). For language learning, the pre-existing capabilities include the state of any of the other languages a learner knows, and the state of any of the learner’s subsystems at one moment in time will determine the learner’s sensitivity to “input” at the next moment in time (Verspoor, Lowie, & De Bot, 2009). This interdependent view also implies that learning is not a gradual and smooth process, but may be abrupt and nonlinear as a result of competition and support between subsystems (Kelso, 2003). In sum, languages do not develop according to a predetermined sequence that is identical for all learners, but emerge as iterations from the system’s self-organizing state space in interaction with its environment. Consequently, language development is a highly individual process.

Many authors refer to changes of the multidimensional state space in terms of growth (Van Geert, 1995). To feed the process of growth of a system, it is dependent on resources. Applied to L2 development, resources comprise the learner’s internal capabilities, such as aptitude and working memory, as well as pre-existing capabilities and motivations. They also include external resources, such as the learner’s environment, time, and material resources (books, TVs) (De Bot et al., 2007). The growth of the system is largely dependent on the availability of resources. “Limitations on resources,” Van Geert argues, “are not only a delimiting factor on what would otherwise be exponential growth, but a crucial ‘driving force’ in development” (2003, p. 656). Focusing on a limited set of connected growers, several authors have simulated language development from a dynamic perspective. For instance, Bassano and Van Geert (2007) have investigated grammatical development by modeling a child’s utterance length recorded from longitudinal data. Their simulations enable them to identify transitions that are indicative of the emergence of grammatical structure and show competitive and supportive relationships between components in the system. Caspi (2010) investigates different levels of vocabulary knowledge using a growth model of longitudinal data of L2 learners of English and demonstrates precursor relationships between receptive and productive knowledge levels. These developments are still in their infancy, but the use of modeling techniques may prove to be a powerful tool to investigate the factors that affect the self-organization of dynamic language systems.

**Nonlinear Development**

Traditionally, SLA is seen as a linear process, with a clear starting point (no knowledge of the L2) and a clear end point (native-like proficiency in the L2). Not all learners will achieve the ultimate goal of native-like proficiency, and those who do not are assumed to
stop developing somewhere along the line. Traditional research has focused on the individual contribution of each of the factors in achieving, or failing to achieve, the ultimate goal.

From a DST perspective, a person’s language is a fully integrated system. Within this framework, it is simply impossible to isolate single factors affecting the process of language acquisition, because the system is more than the sum of all these factors. Motivation, aptitude, and all the other “factors” are strongly interacting components or subsystems within the system, and they change as a function of the system’s previous point of development within a developmental context. And since the context in which the system operates is again a system in itself, any change of the language system will also change its context. In principle, a dynamic system can show linear development, but real-life dynamic systems tend to be complex, as they emerge from the interaction of the components of the system and the context in which they develop. The development of complex dynamic systems can therefore be described as nonlinear (Van Geert, 2003). While linear relationships are strictly proportional, nonlinear relationships are not proportional and are therefore unpredictable.

Nonlinearity in L2 development is best illustrated by contrasting a linear view and a nonlinear view. In a linear understanding, the learner’s development is essentially the sum of all the factors affecting the learner. The assumption is that if we knew all of the learner’s characteristics, such as aptitude, motivation, anxiety, age, learning strategies, the input, and all other external and internal influences (which of course is purely hypothetical), the learner’s development could be predicted. From a nonlinear point of view, this would not be possible, because each subsequent iteration of a dynamic system develops as a function of the interaction of its subsystems in constant flux with the environment. For instance, at moments that are characterized by high levels of anxiety, the amount of motivation may simply be irrelevant. Similarly, successful social interactions may dramatically increase the learner’s motivation. In other words, a change in motivation at one point in time may trigger a change in any of the other subsystems at the next point in time. Consequently, the individual contributions of each of these interactions cannot explain the development. Or as Van Geert puts it, “the effect of a dynamic process differs from the sum of its parts” (2003, p. 657). This also means that from a DST perspective, language does not develop in predetermined structures or a representative design. Rather, language development emerges from the interaction of its components, each of which has its own timing properties and each of which dynamically interacts with its contexts.

This “unruly” behavior of the system is referred to as chaos. Although this term is commonly interpreted as “completely random” in everyday language use, chaos in the DST sense of the word is not the same as random behavior, as there are limitations and forces that may push the system in a certain direction (see “attractors,” above). It rather means that the development is nondeterministic, or stochastic.

The nonlinear, erratic patterns of development are often manifested in a great deal of variation found in learner data. Longitudinal studies into aspects of L2 development have demonstrated the nondeterministic nature of development and have shown the relevance of variability. An early example of a study concentrating on learner variability is the work done by Cancino, Rosansky, Schumann, & Hatch (1978), who, in the vein of other studies in that era, attempted to explain the variability in their data in terms of external influences. A recent micro-genetic reanalysis of their data using a DST perspective (Verspoor, Lowie, & Van Dijk, 2008) shows that the amount of variability strongly fluctuates between progress and decay (“acquisition” and “attrition”). The analyses also show that increased variability leads to a subsequent increase in development, but not linearly and only as a function of the dynamic interaction of factors over time. As Larsen-Freeman puts it, “there are no discrete stages in which learners’ performance is invariant, although there are
periods in which certain forms are dominant . . . There appears to be a need for the necessary building blocks to be in place in sufficient critical mass to move to a period where a different form dominates” (2006, p. 592). This observation accounts for the necessity of variation in learner data. Variability in the learner’s system can be seen as a precursor condition to making progress.

The relationship between the amount of intra-individual variation and language development was also shown in a study by Van Dijk and Van Geert (2007) on the development of spatial prepositions. Using analytic techniques such as ProgMax and RegMin, these authors show that developmental transitions in their data are characterized by discontinuities of intra-individual variability. While in traditional approaches to L2 development variability is often regarded as undesirable noise that blurs the “true score” and that stands in the way of finding significant differences between groups or conditions, DST regards variability as an essential characteristic of the system’s process of self-organization that may signal changes and transitions. From an evolutionary perspective, we could even say that nothing would ever change if there were no variation.

An important implication of its chaotic, nonlinear, and highly variable nature, is that there is no end state of language development. While a native speaker variety may be a learner’s ultimate goal and could be seen as one of the attractors of the system, it is not the system’s only attractor. Neither is it likely that all of the components of a dynamic system reach an attractor state simultaneously. If this happened, we could speak of true fossilization. But given the availability of sufficient energy and optimal circumstances (e.g., attention, motivation, and practice), an attractor state is not irreversible. Moreover, even a seemingly stable state may still show a considerable degree of variability. The development (progress or decay) of the dynamic language system takes place at many different timescales, from decades to milliseconds. At the decade level, the language system is greatly affected by important socioeconomic events in life, from the first school years to marriage, migration, and retirement (Lowie, Verspoor, & De Bot, 2009). At the millisecond level, language is affected by recency and associations of language forms in the context of their use (Lowie, Verspoor, & Seton, 2010). Seen in the light of the constantly changing and chaotic properties of a dynamic language system, simultaneously affected by social and cultural variables, affective variables, age-related variables, and crosslinguistic variables, the continuous development of the language system may temporarily slow down in some of its subsystems, but is unlikely to ever come to a halt.

Conclusion

As many authors have argued, the main characteristics of dynamic systems, such as interconnected subsystems, self-organization, and nonlinear development, are in line with the observed dynamic nature of L2 development (Larsen-Freeman, 1997; De Bot et al., 2007). The application of DST to L2 development is very recent, and in spite of a boost of research using this framework in the past few years many questions still remain to be answered, partly because the framework has not yet been fully developed. For instance, the very nature of linguistic subsystems, including the subsystems of different languages, needs further elaboration. From a DST perspective, subsystems cannot be regarded as closed modules that operate independently, but the precise nature of the way in which different languages are embedded in the system is as yet unclear. Both neurolinguistic and psycholinguistic studies are needed to resolve this issue. Also the nature of representations needs further attention. If Spivey (2007) is correct, and there are no things in the mind but only processes, the firmly established distinction between procedural knowledge and declarative knowledge can no longer be maintained, and even deeply rooted distinctions like syntax versus lexicon will need to be abandoned (see Elman, 2011).
This is why many authors working in the DST field of L2 development have argued that a new start must be made after a century of theory formation about language and language development. Even though both theory formation and empirical work can be expected to develop rapidly in this field, dynamic models of language cannot be developed overnight. Not only is theorizing needed, but also new research paradigms must be developed to investigate language perception and production within a continuity-of-mind framework. For instance, computer modeling of L2 data is promising, but needs further development. The strongly reductionist computer models may reveal very relevant aspects of dynamic relationships in L2 development, but tend to be limited in their implications. Traditional approaches to L2 development have often reduced the acquisition process to a series of discrete events. Proponents of a DST approach to L2 development argue for the recognition of language development as a continuous, multidimensional process. This view will require a further change from product-oriented research to process-oriented research and implies a need for more micro-genetic longitudinal studies over longer periods of time. Such studies will allow for analyses using advanced statistical techniques like autocorrelation and time series.

And finally, the new insights may result in the adjustment of language teaching practices. If language development is indeed a highly individual process, language pedagogy will have to accommodate this. Language pedagogy will also have to take it into account that learning entails changes in a self-organizing system. This implies that languages cannot be taught in an “information processing” sense of the word, but that language teaching can only aim at creating optimal conditions and perturbations that invoke the desired phase changes in the multidimensional state space of what we simply call “language.” There is nothing simple about that.

SEE ALSO: Chaos/Complexity Theory for Second Language Acquisition; Variability in a Dynamic System Theory Approach to Second Language Acquisition

References


Suggested Readings