The Origins of Vowel Systems (henceforth OVS) by Bart de Boer is the first publication in an Oxford Linguistics series that features studies in the evolution of language. Being a field linguist primarily concerned with the acoustic differences of existing vowel systems, I was intrigued by the book’s title and thus curious to see what fresh insights I might glean from considering language from an evolutionary perspective. OVS, however, is not about the biological evolution of language but rather about how the principle of self-organization in a population might explain the kinds of language universals found in human languages, more specifically universals of vowel systems. De Boer’s claim is that these universals can be explained as the result of two phenomena: functional pressures on the system and the dynamics of a population of language users and learners. Within such a context, the regularities and universal tendencies which emerge are the result of self-organization.

The research presented in OVS is based largely on de Boer’s 1999 Ph.D. dissertation (available at http://uvafon.hum.uva.nl/bart/publications.html), a work that had computer scientists and researchers of artificial intelligence as its primary audience. While this work promises to retain the interdisciplinary nature of the earlier work, i.e. being informed by both phonetics and the field of artificial intelligence, it also promises not to overwhelm an audience with less knowledge of computer modeling and programming.

Nonetheless, for someone like myself, with little prior knowledge of artificial intelligence research and computer modeling, the learning curve is still steep. De Boer does help the reader, though, by defining or delimiting a few terms. For example, he explains that the field of artificial intelligence is divided into two kinds of research: one concerned with creating smarter computer programs and the other with using computer models to understand human intelligence. Since language is deemed to be an essential part of human intelligence, the research in this book falls into the latter camp. As such, the research de Boer conducted relies heavily on computer simulations. In Chapter 4, which we will return to below, the basics of the computer simulations used in the research are presented and in Chapter 5 the results of those simulations are summarized.
In Chapter 3, de Boer devotes an entire chapter to the term “self-organization.” This term he defines as “the emergence of order on a large scale in a system through interactions that are only on a large scale” pg. 25. Self-organization, he claims, occurs when the global behavior of a system depends both on the behavior of the parts as well as the interactions between those parts. As self-organization is a natural phenomenon occurring in many different systems in nature, de Boer gives examples from physics, chemistry and biology. The easiest examples of self-organization to understand are those from the animal kingdom, the honeycomb being an especially good one. In a honeycomb, no centralized force guides bees to build a regular hexagonal structure; rather, interactions between individual bees, all who have similar size and force, working near each other (called local interactions), cause the hexagonal grid to emerge. This example especially illustrates the importance of the interplay between individual behavior and the interactions of individuals. No one bee can reproduce the hexagonal structure of the honeycomb; it results from the global behavior of a population of bees.

Included in the concept of self-organization is the understanding that the number of states in which a system can exist is limited. That is, regardless of the number of unordered states a system can potentially start in, there will be an evolution toward a more limited set of ordered states. However, for self-organization to take place there must be dynamics (which is how a system changes over time) with positive feedback. These two together are a force which causes a system moving in a certain direction to continue doing so. In a self-organizing system where the dynamics and positive feedback operate within bounds, the system moves towards a possible stable state (called an attractor). In the simplest systems there is only one possible stable state, but in complex (non-linear) systems, there are many and at times unpredictable outcomes. In addition, there are both closed and open dynamic systems. A closed system does not interact with outside forces, while an open system does.

As de Boer points out, language is a perfect example of a complex open dynamic system. Individual language users comprise the interacting elements and the local interactions are those speakers interacting with each other and learning the language from each other. As in the construction of the honeycomb, there is no central force controlling the language (although it might be argued that language academies or other prescriptionists certainly try to do so) and thus self-organization can result. Language is an open system because the population of language users is not static and because innovation occurs, itself due to the need to interact with changes occurring in the outside world.

Language is therefore an adaptive system which can change in order to optimize communicative efficiency, effectiveness and ease of learning. But no one individual speaker performs such optimizations; they are the result of local interactions, wherein, for example, things that are easier to learn and which occur more frequently will be learned first, but harder or less frequent things are more likely to be lost from the language. Positive feedback is the mechanism by which new words or expressions can spread throughout a community of speakers. For example, “email,” “cell phone” or “land line” were not words or expressions that I knew or employed during my childhood or early adulthood, but are staples in my and my language community’s current vocabulary.
It is within this context of language as a collective behavior (inspired by the work of Steels and others) that the computer simulations described in Chapter 4 take place. De Boer states that the purpose of the simulations is “to investigate the emergence of a vowel system in a population of agents that learn to imitate each other as successfully as possible with an open system of vowel sounds” pg. 40. The study seeks answers to two questions: one, whether a population is capable of building a coherent set of vowels from scratch and two, whether the vowel sets that emerge show the kinds of universal tendencies that human vowel systems do.

A major goal of the simulations was to make the agents’ production, perception and learning of speech sounds as human-like as possible. To do so, the agents were equipped with three things: an articulatory vowel synthesizer, a realistic model of perception, and a memory to store a vowel set. A prototypical vowel had stored with it the values for position, height and rounding as well as an acoustic signal consisting of the first four formant frequencies with which incoming signals were compared. A certain percentage of noise was added to the synthesis in order to simulate the slight perturbations that occur in articulation, environmental noise or speaker variation. The perception model had built into it a means for calculating the distance between vowels based on the F1 frequency and an effective F2’ – a weighted sum of the second, third and fourth formants based on a critical distance between formant peaks. This distance function was used to calculate the distances between the incoming signal and the stored acoustic prototypes of the vowels.

The simulations themselves were carried out in a series of imitation games wherein two agents have the goal of imitating each other as well as possible using a repertoire of sounds that is as large as possible. Depending on the outcome of the game, agents will update their systems. A simple example of how this works is as follows. Two agents randomly chosen from a population play the imitation game. One is given the role of initiator and the other imitator. The initiator has a vowel inventory of /i e a o u/ while the imitator has an inventory of /i e ɑ o u/. The initiator randomly chooses a vowel from its inventory (say /a/) to which noise is added and the outcome is [ɐ]. The imitator evaluates the acoustic signal of this sound to the values stored with its prototypes and chooses /ɑ/ to which noise is added and [ɒ] is produced. The initiator analyzes this sound as /a/ and so the game is a success. If, however, [ɒ] is perceived as closer to /o/, then the game is considered a failure.

Chapter 5 presents the results of the simulation games. The most striking result is the degree to which the emergent vowel systems resemble F1 vs. F2 formant plots of live languages. For example, in a population of 20 agents playing 4,000 games with 10% noise factored in, the emergent clusters resemble the scatterplot of a typical V-shaped five-vowel system. Included in Chapter 5 is also the analysis of the simulation results, including the success of imitation, analysis of the emerged systems, comparison with random systems (systems not generated via imitation games), and with optimal systems (ones in which the energy of the resultant system is minimal and the vowels maximally dispersed). It is shown that systems obtained from the imitation games compare more favorably with optimal systems than systems that were generated randomly.

De Boer tests Steels’ theory of language as an adaptive open system (Steels 1997, Steels 1998 and Steels 1999) by introducing changes into the population within the simulations. This is done
by adding new agents and removing old ones and by introducing an age structure. These changes simulate the kinds of phenomena found in human populations, namely births and deaths or by giving young agents a large step size (number of practice steps) so that they imitate new vowels more quickly than older agents and by giving older agents a smaller step size which provides stability within the system. De Boer discovered several things: 1. changing populations produce fewer vowel clusters than populations that do not change, 2. changing populations cause the emergence of a vowel system (from scratch) to occur more slowly than in unchanging populations, and 3. populations with an age structure preserve vowel systems better when the number of practice steps is limited.

The most interesting sections of Chapter 5 are those which compare the similarities of the vowel systems emerging from the simulations with existing human vowel systems. In these sections, de Boer fleshes out the basics of the language universals and typology of human vowel systems he presented in Chapter 2 and discusses what predictions a theory claiming to model the emergence of vowel systems should make. De Boer’s comparisons refer to two typologies: Crothers’ (1978) typology based on the Stanford Phonology Archive, which consists of 209 languages, and Schwartz, Boë, and Vallée’s (1997) typology based on the UPSID317. In particular, the simulations’ vowel systems are compared to the first twelve of Crothers’ universals for vowels. For example, 51 systems with four vowels and 49 systems with five vowels emerged via simulation. All of the four-vowel systems conform to Crothers’ first universal (all languages have vowels /i a u/). Of the five-vowel systems which emerged, the most common one (the symmetrical five-vowel system) conforms not only to Crothers’ first universal, but also to universals 2 and 3—all languages with four or more vowels have /i/ or /e/ and languages with five or more vowels have /e/ and tend to have /o/. The emergent symmetrical five-vowel system also conforms to Schwartz, Boë, and Vallée’s finding for the UPSID317, occurring 88% of the time in the simulation run and in 89% of the languages with five vowels in the UPSID317.

De Boer’s OVS is not limited to the results of his investigation into emergent vowel systems. There is fuel for thought for linguists specializing in other domains of linguistics. For example, the remaining two chapters of OVS explore how the simulated evolution of language might be applied to other domains, such as the modeling of syntax and semantics or to other aspects of sound systems, such as consonants. Ways in which language dynamics might be investigated with computer modeling are also suggested. This section (6.3) should prove of particular interest to the sociolinguist studying the behavior of language communities.

References


