Review


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Abstract

This book presents a comprehensive investigation into the emergence of sheared vowel systems in a population of simulated language users. De Boer shows clearly and convincingly how simple interactions between individuals can result in the development of linguistically plausible vowel systems, without any need for innate pre-specification or centralised control.

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1. Introduction

In The Origin of Vowel Systems, the first book in the flourishing Oxford series Studies in the Evolution of Language, Bart de Boer investigates human vowel systems, and argues that their emergence and universal properties can be explained through self-organisation. De Boer, now Assistant Professor of cognitive robotics at the University of Groningen, presents a detailed computational model designed to simulate linguistic interactions between artificial language users, known as agents. Using this model, he demonstrates that efficient and cross-linguistically plausible vowel systems can emerge and be shared by a population of agents, without any need for the system to be either pre-specified in the agents’ minds, centrally controlled, or explicitly optimised. Instead, the systems and the universal tendencies they contain are seen to emerge naturally from the agents’ repeated interactions, in the form of simple imitative language games.
2. Summary

*The Origin of Vowel Systems*, an extension of de Boer’s Ph.D. thesis, is divided into seven chapters. In chapter 1, de Boer briefly introduces and sets out the scope of his project, before moving on in chapter 2 to consider the universals and regularities found in sound systems across the world’s languages. He summarises and criticises previous work which has attempted to provide explanations for vowel system universals, arguing that many of these explanations show only why a certain system is optimal, given certain functional criteria, but do not demonstrate how this optimisation might occur; *The Origin of Vowel Systems*, then, is his attempt to rectify this oversight.

In chapter 3, he explains his proposed mechanism for the emergence of shared vowel systems which reflect language universals, namely self-organisation: order at the macroscopic level is explained by simple interactions on the microscopic level. Self-organisation, of course, is an extremely powerful force which abounds in nature: de Boer notes the well-known behaviour of social insects such as ants and bees, where a simple tendency in each individual insect, for instance to ‘follow the pheromones’, leads to the creation of efficient paths to food sources, without the need for any guiding hand controlling the whole system. De Boer applies self-organisation to the linguistic sphere, in order to investigate whether individuals’ local linguistic behaviour translates into global properties of the system in a non-trivial way. He considers how language can be viewed as a complex adaptive system, which is being implicitly optimized in many directions at once. In particular, he suggests three dimensions along which language is constantly changing: communicative efficiency, or not expending more effort than is necessary in production; communicative effectiveness, or maximizing the hearer’s understanding of the utterance; and ease of learning. These proposed dimensions of change find an interesting echo in other accounts of language change, for instance in Deutscher (2005)’s forces of destruction and creation.

In chapter 4, de Boer provides a robust and thorough justification for his choice of computer simulations as an experimental tool, and then sets out clearly the aims of the specific experiments he will carry out. Computational simulations are a valuable tool primarily because they impose rigour on experiments, and allow experimenters to test certain aspects of the system explicitly and in detail, to discover which factors and interactions in the model are important in order to explain a phenomenon. Our intuitions about the behaviour of complex self-organising systems are notoriously inaccurate, and, as de Boer points out, it is not always easy to see exactly what macroscopic behaviour is predicted by many linguistic theories. The aim of de Boer’s simulations is to investigate whether a population of agents can settle on a coherent system of vowels, and then further to explore the extent to which the emergent systems show the same universal tendencies as those found in natural languages. Going back to the first principles of communication, therefore, de Boer makes the agents’ abilities very simple: to identify and attempt to imitate the sounds produced by the other agents. To this end, each agent is able to produce, perceive and store a repertoire of simple vowels; both the production and perception mechanisms are designed to be as similar to human systems as possible. Vowels are represented as prototypes, using the basic articulatory features of position, height and rounding, but ignoring secondary features such as nasalisation, length and diphthongisation. In production, this articulatory representation is converted to an acoustic representation based on the first four formant frequencies, with the addition of noise to ensure that no two signals are exactly the same. Vowels are perceived as instances of the vowel prototype which is nearest to the signal; the distance between vowels is calculated in a modified two-dimensional acoustic space, in which the second, third and fourth formants are merged into an ’effective second formant’.
The interaction between two agents is limited to an idealised episode of imitation, based on the language games designed by Steels (1995). An episode consists of four separate, pre-defined stages of production, imitation, evaluation and modification:

1. The first agent (the initiator/speaker) utters a vowel chosen at random from its repertoire.
2. The second agent (the imitator/hearer) hears this vowel, checks it against its own repertoire, and produces the prototype which is closest to the signal it heard.
3. The speaker indicates to the hearer extra-linguistically whether the imitation corresponds to the speaker’s original vowel.
4. Both agents update their vowel repertoires based on the outcome of the episode.

Each vowel in an agent’s repertoire has an associated score, which is increased slightly when it is used in a successful imitation game. Conversely, the failure of an imitation leads to a reduction in the vowel’s score, and the hearer also either ‘learns’ the vowel it heard, by adding a new vowel to its repertoire, or adjusts the position of the unsuccessful vowel it used. In addition, each agent regularly performs basic housekeeping tasks on their individual repertoires, removing vowels which are used very infrequently, merging vowels which are very close to each other, and occasionally adding vowels at random. These local modifications serve to facilitate the development of a shared system which maximises the use of the articulatory space: the feedback on the imitation game encourages agents to use and keep vowels which are successful, and therefore shared by the agents, while the addition of noise into the system introduces confusion between vowels which are close together, and so results in their relative lack of success compared to vowels which are further apart, and therefore to their being pruned from the system.

Having described the structure of the simulation in admirable detail, de Boer moves on to present a comprehensive analysis and interpretation of his findings in chapter 5. He starts with a population of agents, all of whom have an empty inventory of vowels, and shows in repeated experiments that the population consistently develops a shared set of vowels. The emergent vowel prototypes are not identical for each agent, but are clustered together, and the systems as a whole certainly appear to resemble realistic natural language systems. De Boer then attempts to analyse the systems which emerge from the simulation more systematically. He first compares them to optimally dispersed and randomly generated systems, using Liljencrants and Lindblom (1972)’s measure of ‘energy’ to measure the dispersion of the system across the vowel space, and using the imitation success rate between all agents to measure the internal coherence of the system. Unsurprisingly, the emergent systems turn out to be more dispersed and more coherent than randomly generated systems, but slightly less dispersed than optimal systems. It is clear, however, that the emergent systems are much nearer the optimal end of the scale, and de Boer appears justified in his claim that the emergent systems are acoustically realistic. He investigates the extent to which the acoustic clusters are reproduced in articulatory space, and finds that although there is indeed articulatory clustering, the clusters are considerably less compact in the three-dimensional articulatory space than the corresponding clusters in the two-dimensional acoustic space.

De Boer also explores the impact of a changing population on the development of a shared vowel system, by introducing the random replacement of agents to model the birth and death of language users. He finds that a vowel system which has been created in a static population is likely to break down when introduced into a dynamic population, because there is more confusion between previously stable vowel clusters, but that a different stable system will
inevitably emerge. On average, vowel systems emerging from dynamic populations are unsurprisingly more fluid, contain fewer vowels, and are less successful than those which emerge from static populations. Importantly, however, a vowel system can still emerge ex nihilo in a changing population, albeit more slowly and with fewer clusters than in a static setup. Secondly, he proceeds to a comparison of the emergent vowel systems with real human vowel systems, classifying them according to their relative position, using the typology described by Crothers (1978). In addition, de Boer investigates the relative frequency of different emergent vowel systems, and compares them to data on natural languages derived from the UCLA Phonological Segment Inventory Database (UPSID) (Maddieson, 1984). Based on these analyses, he maintains that his emergent systems “correspond very well with the types of vowel systems that are most often found in human languages” (p. 104).

The book finishes with de Boer seeking both to position his work in a wider context, and to explore the implications of his results. In chapter 6, he describes research by other modellers who are exploring the evolution of different aspects of linguistic structure, notably the emergence of syntax-like structure and the coupling of words with semantic representations. Inevitably, given the considerable recent increase in work in this area, this summary is now slightly dated, though nonetheless valuable as a historical overview of the field.

In the final chapter, he speculates on how his efforts in showing the effectiveness of considering sound systems as dynamic, self-organising social constructions might provide a framework for explaining more complex linguistic phenomena. For example, he discusses the potential for self-organisation to be used in explanations of word order preferences, tonogenesis, and the development of voicing distinctions.

3. Evaluation

The Origin of Vowel Systems claims two key results: first, that stable and functional vowel systems can emerge through self-organisation, and second, that these emergent vowel systems show the same universal tendencies as are found in natural languages.

The orthodox nativist view, of course, is that the structural features which all languages have in common are determined directly by the innate cognitive mechanisms which support language in each individual. Pinker and Bloom (1990) therefore argue that the human brain must have evolved to contain these mechanisms because of the functional advantages which are gained by humans who have linguistic competence. Under this view, accounting for the evolution of the cognitive mechanisms supporting language is equivalent to accounting for the evolution of language itself, and the job of the evolutionary linguist is to provide a plausible pathway for such biological evolution to have taken place. In contrast, de Boer approaches the problem by trying to identify which phenomena need to be explained biologically. He divides the target of explanation into elements which must be explained in terms of biological evolution (such as the human vocal tract), and those which may better be accounted for in terms of other processes. The great advantage of such a technique is that, by explaining putatively innate aspects of language through non-biological mechanisms, it makes the problem of explaining what has evolved biologically much more manageable, and, ultimately, much more plausible. This strategy is increasingly common among linguists interested in the question of language evolution, as can be seen from this recent rallying cry from Ray Jackendoff: “If some aspects of linguistic behavior can be predicted from more general considerations of the dynamics of communication in a community, rather than from the linguistic capacities, then they should be.” (Jackendoff, 2002:101). It is important to remember, therefore, that in The Origin of Vowel Systems, de Boer is not directly
concerned with providing an explanation of the biological evolution of the human capacity for
language, but is instead concerned with circumscribing such an explanation.

The strength of De Boer’s claim on emergence, therefore, lies in the fact that his agents are not
required to have unrealistic innate abilities; there is no pre-specification of the vowel system, and
no need to have access to the internal representations of other agents, yet shared systems
inevitably emerge. On the other hand, his model does assume that agents understand and will
participate in structured, co-ordinated, interactive episodes, which are designed to be reasonably
complex and distinctly communicative in nature. Even this, however, is not an insurmountable
problem, and indeed recent work by Oudeyer (2005, 2006) has eliminated the assumption of pre-
existing interactive behaviour, and thereby demonstrated that speech codes can emerge in a
society of agents who do not possess any existing communicative or social skills at all.

De Boer’s secondary claim, that the emergent vowel systems reflect the same universal
tendencies as human languages, appears to be more questionable, given the evidence presented.
While it certainly seems superficially plausible, the analysis of the vowel systems in chapter
5 on which this claim is based rests unduly on what appear to be rather impressionistic
classifications of the vowel systems. In addition, there is insufficient explanation of exactly how
the comparison with Crothers’ analysis is undertaken, and of how a particular system might be
considered sufficiently similar to Crothers’ rules to count as a successful match, which gives the
(probably erroneous) impression that the analysis is somewhat ad hoc. For instance, de Boer himself
notes that the agents in his system have a problem learning high front vowels, which are often rather
more retracted than might be expected. We have already seen that the feedback mechanism
effectively maximises the use of the available space, and so this artificial retraction of a high front
vowel has the knock-on effect of lowering high back vowels somewhat. Despite this, however, de
Boer still labels the emergent triangular three-vowel systems as /i,a,u/, so conforming to Crothers’
typology, rather than using a classification of something like /i,a,o/, which would seem a more
appropriate labeling of the system to the casual observer. While this may be explained away as an
artefact of the system, de Boer also cites Crothers’ second ‘rule’, that in addition to /i,a,u/, a four-
vowel system will also contain /i/ or /e/, in support of the claim that his emergent four-vowel
systems are “much more realistic” (p.93), despite the fact that none of his emergent systems
actually contain both /i/ and /e/ at all. It is a pity that a more precisely defined and consistent method
for assigning phonetic symbols to a particular cluster was not used, both in de Boer’s emergent
systems and in the data originally analysed by Crothers (1978). This would have served to make the
claims on universal patterns more quantifiable, more comparable to potential future work in which
vowel systems are simulated, and ultimately much more compelling.

But these are relatively minor issues, which should not lessen the main impact of the book as a
whole, which provides a thoroughly enlightening and important analysis of how complex vowel
systems can develop in a society of language users, without any centralised control or innate pre-
specification of the system. De Boer’s exposition of his experiments is lucid and comprehensive,
containing sufficient detail to allow them to be replicated by those keen to extend and develop the
work, while not overwhelming the reader with unnecessary technicalities. The Origin of Vowel
Systems will be an invaluable resource to all researchers interested in language evolution, in
particular to those interested in exploring the dynamics of developing linguistic systems and in
building working computational models of language use.

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References


