1. Introduction

Language defines humanity. It is generally agreed that what distinguishes humans from other animals is their intelligence and their ability to talk. Intelligence, however, is often defined in terms of language. The well-known Turing test, designed by Alan Turing (Turing 1950) to decide whether a computer program is intelligent, is based on the computer's ability to use language. Ethnic identity is also often defined by language. In Tok Pisin, the lingua franca of Papua New Guinea, the word for referring to people of one's ethnic group is *wantok*, 'one talk', meaning the people that speak the same language. The Slavonic peoples refer to the German people as *nemec* (for example, Russian немец), 'those who cannot speak'. The ancient Greeks called the Persians (and probably all other peoples as well) βαρβαροι, 'barbarians', supposedly because all they heard when they heard the Persian language were unintelligible sounds: 'Barbarbar . . .'. Language is essential for humanity.

Human languages are extremely diverse. Today, some 6,000 languages are spoken around the world. Although many of these languages are obviously related to each other, and can be grouped into large language families, such as Indo-European, Tibeto-Burman, or Austronesian, the links between the language families are much more difficult to establish. It is possible to reconstruct relations between languages up to a depth of approximately 8,000 years with currently accepted scientific methods. Beyond this time span, so much information is lost that reconstruction becomes speculative. As *Homo sapiens* has existed for more than 200,000 years and has been spreading around the world for at least 100,000 years, current linguistic knowledge suggests that many human languages have to be considered as historically unrelated.

Nevertheless, unrelated languages can have similarities in all respects: in their sound systems, their syntax, their morphology, their colour terminology, and also, for example, in the way they change over time. The similarities that occur in many unrelated languages and that cannot be attributed to chance are called *universals*. Originally, a language universal denoted a property that all human languages possess, but as very few such properties can be found, the term is now used for properties that occur in many (but not necessarily all) human languages. Sometimes the term 'universal tendency' is used. The study of universals can teach us about what human language is, what its constraints are, and how it is linked to other cognitive capacities of the brain. It is also important to investigate what can cause these universals. Chance and historical or geographical relations must be ruled out. Possible explanations can then be based on properties of the human brain, the function of language, or on historical processes. An understanding of what language is and what factors shape it will aid our understanding of the origin of language.

The origins of language and its diversity have always been subjects of speculation. Traditionally, language fell within the domain of religion. Language was usually seen as a gift (and its diversity a damnation) of the gods. Since the Renaissance, scientists too have started speculating about the origins of language (see, for example, Rousseau reprinted 1986; Jespersen reprinted 1968). Most of the early speculation was rather impressionistic. More recently, with advances in archaeology, neurology, and linguistics, speculation on the origins of language has become more grounded in facts (see, for example, the contributions in Hurford *et al.* 1998).

This book contributes to the study of the origins of language by investigating universals of human vowel systems and explaining them as the result of functional pressures and the dynamics of a population of language users and learners. It will be shown that in such a situation, regularities and universal tendencies can emerge as the result of self-organization. It should be noted that the language users in this framework are already capable of producing, perceiving, and learning vowels in the same way as modern humans can. The theory that will be outlined in this book is therefore strictly speaking not about the *biological* evolution of language. Rather it proposes a different mechanism (self-organization in a population) for explaining universal properties of human languages. The implication for theories of the biological evolution of language is that all phenomena that can be explained by other mechanisms do not have to be explained as the result of biological evolution, thus making the explanation of the evolution of language easier.

The goals of the research described here were twofold: first to investigate what mechanisms might be necessary for explaining the universals of human vowel systems and secondly to investigate what the role of the population might be in the explanation of linguistic universals. The research was part of a Ph.D. project (de Boer 1999) in artificial intelligence, which was part of a larger research effort to investigate the origins of human intelligence (Steels 1999). One can divide artificial intelligence research into two kinds: one that is aimed at constructing more intelligent computer programs and another that is aimed at using computer models to understand human intelligence. The research described here is part of the latter. As has been pointed out above, language is generally considered to be an essential part of human intelligence, and therefore learning about the origins of language is of interest in order to learn about the origins of intelligence.

As the research was conducted in the tradition of artificial intelligence, it is characterized by strong emphasis on computer simulations. Generally, theories in artificial intelligence are not accepted unless they can be shown to work in a computer simulation. By contrast, in linguistics research, results from computer models are still sometimes regarded as uninteresting and irrelevant to the study of human language. Another goal of the research described in this book is therefore to show that computer models of language can give interesting and relevant results.

The text of this book is based in large part on the text of the Ph.D. thesis. However, as this text was originally aimed at computer scientists and researchers in the field of artificial intelligence, it has been adapted extensively to an audience that has less knowledge of computer modelling and programming. In order to retain the interdisciplinary nature of the work, linguistic, phonetic, and phonological jargon is kept to a minimum and such jargon as is used is explained where necessary. Such explanation might be tedious for readers with a more linguistic background, but I pray them to excuse me.

This book consists of seven chapters. Chapter 2 introduces the universal properties of human vowel systems and the explanations for these that have been put forward by researchers over the years. Chapter 2 also discusses some earlier computer models that were intended to explain the universals of vowel systems. This chapter explains how the theory and the simulations presented here address the drawbacks of the previous theories and models. Chapter 2 presents the linguistic background to the research discussed in this book.

Chapter 3 explains the phenomenon of self-organization that is found in many complex systems in nature, and argues that it is very likely that self-organization also plays a role in the origins and the history of human language. The chapter continues with an explanation of the theories of Steels (Steels 1997*b*, 1998*a*) on language as an open, complex, adaptive system and the mechanisms that might be responsible for its origins. Finally, there is a section on the implications of self-organization for the study of the evolution of language. Chapter 3 provides the necessary background for understanding the mechanisms that are used in the theory and the computer simulations.

Chapter 4 describes the computer simulations in sufficient detail for them to be reproduced. However, an attempt has been made to present the models in such a way that readers who do not know much about programming will also be able to grasp the essentials of the model. A basic understanding of this chapter is essential for appreciating the results presented in this book and how they have been achieved as well as for appreciating why computer simulations are of use.

Chapter 5 presents the results of the computer simulations. It is shown, first, that the computer simulations actually work, and then that the emerging vowel systems are close to optimal and far from being random. The implication of this finding is that what occurs in the simulations is significant. The chapter then presents a variation on the basic simulation, in which the populations of agents change and have an age structure. These variations illustrate two things: first, in a computer simulation, it is easy to make small changes in order to investigate phenomena that might be extremely hard to investigate in real languages. Secondly, the results of the simulation are robust: variations in the details of implementation do not change the qualitative outcome. Finally, the systems that emerge from the simulations are compared with human vowel systems and it is shown that the relative frequencies of the systems that emerge correspond remarkably well with those of the vowel systems found in human languages.

The next two chapters are of a more general nature and do not appear in the Ph.D. thesis on which this book is based. Chapter 6 presents a selection of other computer modelling work on the origins of language. The selection itself is not complete and is mostly drawn from work with which I am reasonably familiar. It is meant in part to illustrate the possibilities of computer modelling for the investigation of the origins of language and in part to make links between this research and the other modelling research that has been done over the last ten years or so. Considered in isolation, the research presented in this book could be viewed as an interesting phonetic curiosity, but it only becomes really interesting when viewed as part of a larger research effort.

Chapter 7 continues in the same vein, but is much more speculative, and looks at the possible implications of the results presented in this book. The first six chapters represent solid results, but in the seventh chapter I explore the possible links between self-organization in vowel systems and self-organization in other parts of language—links that are not, however, based on such results. The chapter first provides an overview of the results presented so far with their implications for universals of vowel systems. It continues by suggesting how the theoretical framework used in this book could be of use for other parts of language. It then explores how more complex sounds could be modelled in the same framework and refers briefly to existing research along these lines. Finally there is an investigation of a tentative link between complex speech sounds and syntax.

Although this book may be somewhat optimistic at times about the role self-organization plays and has played in the origin of language and the explanation of its universals, it is not my intention to propose that this mechanism can explain everything about language. Language in general and individual languages in particular are complex phenomena whose origins and history have been influenced by many different factors as well as random events. However, I wish to show that self-organization in a population, as a process separate from biological evolution or innately determined development, can explain properties of vowel systems in an elegant way and that it is probably useful as a way of looking at other aspects of language as well.