Language Evolution

Edited by
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Preface

In January 2000, we were invited by Janet Wiles and her colleagues to speak at the Workshop on Evolutionary Computation and Cognitive Science arranged in connection with the Fifth Australasian Cognitive Science Conference in Melbourne. It was one of those trips that remind you why you became an academic. The weather was wonderful; Melbourne is a great city, and Janet, as anyone who knows her will attest, is a fantastic host. The workshop was fascinating, and led us to the realization that language evolution really was a research topic whose time had come.

On one of our free days, we set off for a hike in the Grampians National Park along with Jim Hurford. In between enjoying the beautiful scenery and being awestruck by Eastern grey kangaroos, kookaburras, colourful parrots, and a blue-tongued lizard, we got talking about how quickly the interest in the origins and evolution of language was growing. It seemed that we were all used to fielding questions about the topic. These queries came from fellow academics, from students, and from interested friends. What were the key issues, the big questions, and the major controversies? Who studied the topic, and what backgrounds did they come from? Most importantly, was there any consensus on how, when, why, and in what manner language evolved?

We realized that we needed a definitive book on the subject: one that we could happily recommend to anyone interested in the area, one that gave the current states of the art, from the big names in every discipline that has a stake in answering these questions, and one that could form the foundation for courses on the evolution of language. This book is the result.

In a street café near St Kilda Beach, we began tackling our first challenge: compiling a list of contributors. This was very hard indeed, because we wished to give as broad a perspective as possible. There were many people we wished we could have included, and would have, had length not been an issue. That said, we think the resulting chapters, along with their further reading sections, should provide a good springboard into the wider, primary literature. The book spans an extensive range of different scientific disciplines, including: anthropology, archaeology, biology, cognitive science, computational linguistics, linguistics, neurophysiology, neuropsychology, neuroscience, philosophy, primatology, psycholinguistics, and psychology. Yet despite having their academic home in such different fields, our authors were overwhelmingly positive in their response to the idea of the book. It thus seems that our belief in the necessity of a collection like this was both timely and widely shared.

It was important for us that the book should be accessible to a wide audience of readers. The authors were therefore asked to provide their up-to-date perspectives on language evolution in as non-technical a way as possible without overly simplifying the issues. To fine-tune the book both in terms of coverage and readability, we gave it a test-run in a combined advanced undergraduate and graduate class on the evolution of language that Morten taught at Cornell University. Every chapter in the book was debated and critiqued in class. As part of the course, students were asked to submit electronic questions regarding each chapter. These e-questions were then passed on to the authors who used them to revise their chapters. Our authors did a great job of incorporating the students' comments and suggestions, improving their already very well written chapters even further. The final result is a very readable volume that also makes an excellent textbook for courses on the origin and evolution of language.

There have been many people without whom this book would have been no more than an idea that we discussed in Australia. In particular, we are indebted to the students in Morten's class. So, many thanks to Mike Brantley, Chris Conway, Rick Dale, Erin Hannon, Ben Hiles, Gary Lupyan, Janice Ng, Makeba Parramore, and Karen Tsui for their very helpful feedback. Others who have helped out along the way include: Jelle Zuidema, Richard Dawkins, and John Maynard Smith. Thanks are also due to John Davey, Jacqueline Smith, and Sarah Barrett at OUP, and to Jim Hurford, who helped get this project off the ground in the first place, and made sure it kept flying.

Very special thanks go out to our loved ones, Anita Govindjee, Sunita Christiansen, and Anna Claybourne, for their patience, encouragement, and support throughout the editorial work on this book.

Finally, of course, we are grateful to our contributing authors. Thank you for your patience with inevitable delays, your readiness to make changes, your enthusiasm for the project, but most of all for your chapters. We think

that together, they will stimulate further interest in and understanding of the origins and evolution of what makes us human: language.

Morten H. Christiansen and Simon Kirby

Ithaca and Edinburgh 2003

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Notes on the Contributors

Michael A. Arbib's first book, *Brains, Machines and Mathematics* (McGraw-Hill, 1964), set the main theme of his career: the brain is not a computer in the current technological sense, but we can learn much about machines from studying brains, and much about brains from studying machines. He currently focuses on brain mechanisms underlying the co-ordination of perception and action, working closely with the experimental findings of neuroscientists on mechanisms for eye-hand co-ordination in humans and monkeys. As in this article, he is now using his insights into the monkey brain to develop a new theory of the evolution of human language.

Derek Bickerton is Emeritus Professor of Linguistics at the University of Hawaii. He originally specialized in creole languages, and developed the controversial 'bioprogram theory' which claimed that these languages are originated by children in a single generation from unstructured input, and represent Universal Grammar in a purer form than do older languages. His major goal at present is to integrate the empirical findings (not necessarily the formalisms) of generative grammar with current knowledge of biological evolution and neurological structure, thereby producing a realistic model of language and its origins.

Ted Briscoe is Reader in Computational Linguistics at the Computer Laboratory, University of Cambridge where he has been a member of staff since 1989. He works on statistical and constraint-based approaches to natural language processing as well as evolutionary modelling and simulation of language development and change.

Morten H. Christiansen is an Assistant Professor of Psychology at Cornell University. His research integrates connectionist modeling, statistical analyses, behavioural experimentation, and event-related potential (ERP) methods in the study of the learning and processing of complex sequential structure, in particular as related to the acquisition, processing, and evolution of language. He received his Ph.D. in Cognitive Science from the University of Edinburgh, Scotland, and has held several interdisciplinary positions before joining Cornell University. He is the editor of *Connectionist Psycholinguistics* (with Nick Chater, Ablex, 2001).

Michael C. Corballis was born in New Zealand and completed his Ph.D. at McGill University in Montreal, Canada, where he taught from 1968 until 1977. He then returned to his present position as Professor of Psychology at the University of Auckland. He has carried out research in a number of areas of cognitive and evolutionary neuroscience, including human laterality, visual perception, the split brain, and the evolution of language. His books include *The Psychology of Left and Right* (with I. L. Beale), *The Lopsided Ape*, *The Descent of Mind* (with S. E. G. Lea), and *From Hand to Mouth*.

Iain Davidson is Professor of Archaeology and Paleo-anthropology at the University of New England in Armidale, NSW, Australia. Since 1988 he has published a book (*Human evolution, language and mind*, CUP 1996) and more than 35 other publications on the evolutionary emergence of language, mostly jointly with psychologist William Noble. His other research work has been concerned with the Upper Palaeolithic, particularly of Spain, and with the archaeology of Australia including its stone artefacts and rock art.

Terrence W. Deacon received his Ph.D. from Harvard University in 1984 with research tracing the primate homologues to cortical language circuits. Since then he has held faculty positions at Harvard University (1984–92), Boston University (1992–2002), Harvard Medical School (1992–2000), and University of California at Berkeley (2002). Professor Deacon's research combines human evolutionary biology and neuroscience, with the aim of investigating the evolution of human cognition. His work extends from laboratory-based cellular-molecular neurobiology to the study of semiotic processes underlying animal and human communication, especially language. Many of these interests are explored in his book *The Symbolic Species: The Coevolution of Language and the Brain* (Norton, 1997). His new book, *Homunculus* (Norton, in preparation) explores the relationship between self-organization, evolution, and semiotic processes.

Robin I. M. Dunbar graduated from the University of Oxford with a B.Sc. in Psychology and Philosophy, and then gained a Ph.D. in Psychology from the University of Bristol. He has subsequently held research and academic posts at the University of Cambridge, University of Stockholm (Sweden) and University College London. He is currently Professor of Evolutionary Psychology at the University of Liverpool, where he leads a research group of 3–5 staff and 12–15 postgraduate students whose research focuses on the behavioural ecology and evolutionary psychology of large mammals (mainly primates and ungulates) and humans.

W. Tecumseh Fitch studies the evolution of cognition in animals and man, focusing on the evolution of communication. Originally trained in ethology and evolutionary biology, he has more recently applied his graduate training in speech science to animal vocal communication. He is interested in all aspects of vocal communication in terrestrial vertebrates, particularly aspects of vocal production that bear on questions of meaning and honesty in animal communication systems, including human language. Fitch received his B.A. in Biology and Medicine and his Ph.D. in Cognitive and Linguistic Sciences, both from Brown University. He joined the faculty at Harvard as a Lecturer in Biology and Psychology in 1999. He conducts research on humans and various vertebrates (including alligators, birds, and monkeys). In 2002 he was a Fellow at the European Institute for Advanced Studies, in Berlin.

Louis Goldstein is Professor of Linguistics and Psychology at Yale University and Senior Research Scientist at Haskins Laboratories. He has developed, along with Catherine Browman, a gesture-based theory of phonology, called 'articulatory phonology'. His research includes experimental work that tests the role of gestures in phonological encoding and development, modeling work on the dynamics of inter-gestural coordination and the different modes of coordination that can be employed in human languages, and simulation work on the self-organization of phonology through mutual attunement of computational agents.

Marc D. Hauser's research sits at the interface between evolutionary biology and cognitive neuroscience and is aimed at understanding the processes and consequences of cognitive evolution. Observations and experiments focus on captive and wild primates, incorporating methodological procedures from ethology, infant cognitive development, cognitive neuroscience and neurobiology. Current foci include studies of numerical abilities, the role of inhibitory control in problem solving, cortical physiology of acoustic processing in primates, the nature of conceptual acquisition in a non-linguistic species, the shared and unique computational mechanisms subserving the faculty of language, and the mechanisms underlying the production and perception of vocal signals in primates. Hauser is a Professor at Harvard University in the Department of Psychology and the Program in Neurosciences. He is the author of three books including, most recently, *Wild Minds: What Animals Really Think* (Holt, 2000).

James R. Hurford has a broad interest in reconciling various traditions in Linguistics which have tended to conflict. In particular, he has worked on articulating a framework in which formal representation of grammars in individual minds interacts with statistical properties of language as used in communities. The framework emphasizes the interaction of evolution, learning and communication. He is perhaps best known for his computer simulations of various aspects of the evolution of language.

Simon Kirby is a research fellow in the Language Evolution and Computation Research Unit at the University of Edinburgh. At the LEC he has pioneered a computational approach to understanding the origins and evolution of language which treats human language as a complex adaptive system. His previous book–Function, Selection and Innateness: The Emergence of Language Universals—is also published by Oxford University Press.

Natalia L. Komarova studied Theoretical Physics in Moscow State University. Her Master's thesis was with Alexander Loskutov on Chaos Control in 2D maps. She received her Ph.D. in Applied Mathematics in 1998 from the University of Arizona, where she studied Non-linear Waves and Natural Pattern Formation under the supervision of Alan Newell. She came to the Institute for Advanced Study (IAS), Princeton, in 1999, as a member at the School of Mathematics, and then she joined the Program in Theoretical Biology (headed by Martin Nowak) at the IAS. She is interested in applying mathematical tools to describe natural phenomena, of which evolution of language is one of the most fascinating and challenging problems.

Philip Lieberman received degrees in Electrical Engineering in 1958 and a Ph.D. in Linguistics in 1966 at the Massachusetts Institute of Technology. His interests have included the prosody of language, voice analysis of laryngeal pathologies, and psychological stress. His primary focus has been on the nature and evolution of the biological bases of human language. This includes studies on the evolution of human speech producing anatomy and the human brain, with special attention to the role of subcortical basal ganglia. His research complements many independent studies that indicate that the neural bases of motor control (particularly speech), syntactic competence, and cognitive ability are interrelated.

Frederick J. Newmeyer specializes in syntax and the history of linguistics and has as his current research program the attempt to synthesize the results of formal and functional linguistics. He is the author or editor of twelve books, including *Linguistic Theory in America* (Academic Press, 1980) and *Language Form and Language Function* (MIT Press, 1998). Newmeyer gained his Ph.D. from the University of Illinois in 1969 and since then has taught in the Department of Linguistics at the University of Washington in Seattle. He served as President of the Linguistic Society of America in 2002.

Martin A. Nowak studied biochemistry and mathematics at the University of Vienna, where he received his Ph.D. in 1989. Subsequently, he went to the University of Oxford to work with Robert May. In 1992, Nowak became a Wellcome Trust Senior Research Fellow and in 1997 Professor of Mathematical Biology. In 1998 he moved from Oxford to Princeton to establish the first program in Theoretical Biology at the Institute for Advanced Study. In 2002, he moved to Harvard University as Professor of Mathematics and Biology. Nowak is interested in all aspects of applying mathematical thinking to biology. In particular, he works on the dynamics of infectious diseases, cancer genetics, the evolution of cooperation and human language.

Steven Pinker received his BA from McGill University in 1976 and his Ph.D. in Psychology from Harvard in 1979. After serving on the faculties of Harvard and Stanford Universities for a year each, he moved to MIT in 1982, where he is currently Peter de Florez Professor in the Department of Brain and Cognitive Sciences and a MacVicar Faculty Fellow. Pinker's research has focused on visual cognition and the psychology of language. In addition to his research papers, he has written two technical books on language acquisition *Language Learnability and Language Development* (Harvard University Press, 1984), and *Learnability and Cognition* (MIT Press, 1989), and four books for a wider audience *The Language Instinct* (HarperCollins/Morrow. 1994), *How the Mind Works* (Norton, 1997), *Words and Rules: The Ingredients of Language* (HarperCollins, 1999), and *The Blank Slate* (Viking, 2002).

Michael Studdert-Kennedy has a BA in Classics from Cambridge University and a Ph.D. in Experimental Psychology from Columbia University. He is Professor Emeritus of Communications at the City University of New York, Professor Emeritus of Psychology at the University of Connecticut and former President of Haskins Laboratories. He has been a research scientist at Haskins Laboratories since 1961, with particular interests in speech perception, hemispheric specialization for speech perception and, most recently, in the ontogeny and evolution of speech.

Michael Tomasello is co-director of the Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany. His research interests focus on processes of social cognition, social learning, and communication in human children and great apes. Books include *Primate Cognition* (with J. Call, Oxford University Press, 1997), The *New Psychology of Language: Cognitive and Functional Approaches to Language Structure* (edited, Lawrence Erlbaum, 1998), and *The Cultural Origins of Human Cognition* (Harvard University Press, 1999).

1

Language Evolution: The Hardest Problem in Science?

Morten H. Christiansen and Simon Kirby

What is it that makes us human? If we look at the impact that we have had on our environment, it is hard not to think that we are in some way 'special'—a qualitatively different species from any of the ten million others. Perhaps we only feel that way because it is hard to be objective when thinking about ourselves. After all, biology tells us that all species are exquisitely adapted to their respective ecological niches. Nevertheless, there is something odd about humans. We participate in hugely complex and diverse types of social systems. There are humans living in almost every environment on earth. We mould the world around us in unprecedented ways, creating structures that can be seen from space, and then going into space to see them.

One of our achievements, especially over the previous century, has been a staggering growth in our scientific understanding of the universe we live in. We are closing in on a complete unitary theory of its building blocks, and we know much about how it started. Yet despite this, our understanding of our place in this universe is far from complete. We still have only a hazy understanding of what exactly it is that makes us human.

Advances are being made, however. The cognitive neurosciences are bringing our view of the brain into focus, and the recent success of human genome sequencing gives us a recipe book for how we are built. However, these approaches to humanity mostly show us how similar we are to other forms of life. The essence of human uniqueness remains elusive.

In this book, we contend that the feature of humanity that leads to the strange properties listed above is language. To understand ourselves, we must understand language. To understand language, we need to know where it came from, why it works the way it does, and how it has changed.

To some it may be a surprise that, despite rapid advances in many areas of science, we still know relatively little about the origins and evolution of this peculiarly human trait. Why might this be? We believe that at least part of the answer is that a deep understanding of language evolution can only come from the concerted, joint effort of researchers from a huge range of disciplines. We must understand how our brains and minds work; how language is structured and what it is used for; how early language and modern language differ from each other and from other communication systems; in what ways the biology of hominids has changed; how we manage to acquire language during development; and how learning, culture, and evolution interact.

This book is intended to bring together, for the first time, all the major perspectives on language evolution, as represented by the various fields that have a stake in language evolution research: psycholinguistics, linguistics, psychology, primatology, philosophy, anthropology, archaeology, biology, neuroscience, neuropsychology, neurophysiology, cognitive science, and computational linguistics. The chapters are written by the key authorities in each area, and together they cast the brightest light yet on questions surrounding the origin and evolution of language.

The Many Facets of Language Evolution

In 1859, when Charles Darwin published his book *The Origin of Species*, there was already a great interest in the origin and evolution of language. A plethora of ideas and conjectures flourished, but with few hard constraints to limit the realm of possibility, the theorizing became plagued by outlandish speculations. By 1866 this situation had deteriorated to such a degree that the primary authority for the study of language at the time—the influential Société de Linguistique de Paris—felt compelled to impose a ban on all discussions of the origin and evolution of language.

This ban effectively excluded all theorizing about language evolution from the scientific discourse for more than a century. The scientific interest in language evolution was rekindled with the conference on 'Origins and Evolution of Language and Speech', sponsored by the New York Academy of Sciences in 1975. However, it took an additional decade and a half before the interest in language evolution resurged in full. Fuelled by theoretical constraints derived from advances in the brain and cognitive sciences, the field finally emerged during the last decade of the twentieth century as a legitimate area of scientific inquiry.

The landmark paper 'Natural Language and Natural Selection', published in 1990 by Steven Pinker and Paul Bloom in the respected journal *Behavioural and Brain Sciences*, is considered by many to be the catalyst that brought about the resurgence of interest in the evolution of language.[1] The paper proposed the theory that the human ability for language is a complex biological adaptation evolved by way of natural selection. In Chapter 2, Pinker updates the theory in the light of new empirical data and the theoretical alternatives that have emerged since the original paper (many of which are represented in subsequent chapters). He lists a number of properties of the language system that give the appearance of complex design. By analogy to the visual system, he argues that the only plausible explanation for the evolution of such complex adaptive design is one that involves natural selection. On this account, language has evolved as an innate specialization to code propositional information (such as who did what to whom, when, where, and why) for the purpose of social information-gathering and exchange within a humanly distinct 'cognitive niche'. In further support for his perspective, Pinker concludes his chapter with a discussion of recent evidence regarding the possible genetic bases of language and the application of mathematical game theory to language evolution (the latter described in more detail in Komarova and Nowak, Chapter 17). The work described in Briscoe (Chapter 16) on grammatical assimilation—an evolutionary genetic adaptation for language acquisition—from the viewpoint of computational linguistics also seems compatible with Pinker's approach.

In Chapter 3, James Hurford agrees with Pinker that humans have evolved a unique mental capacity for acquiring language, but disagrees with him over the role of cultural transmission (learning) in explaining language evolution. Hurford argues that language evolution needs to be understood as a combination of both biological pre-adaptations—that is, biological changes that may not be adaptive by themselves—and learning-based linguistic adaptations over generations. He points to several possible biological steps prior to the emergence of language: pre-adaptations for the production of speech sounds (phonetics), for organizing the sounds into

[1] According to the ISI Web of Knowledge index, the rate at which language evolution work appears in the literature increased tenfold in the decade following the Pinker and Bloom paper. Thus, when counting the papers that contain both 'language' and 'evolution' in title, keywords, or abstract, the publishing rate for 1981–1989 was 9 per year, whereas it was 86 per year for the period 1990–1999, and 134 per year between 2000 and 2002.

complex sequences (syntax), for forming basic and complex concepts and doing mental calculations with them (semantics), for complex social interaction (pragmatics), and for an elementary ability to link sounds to concepts (symbolic capacity). Once humans were language-ready with these pre-adaptations in place, language systems would have grown increasingly complex due to the process of transmitting language across generations through the narrow filter of children's learning mechanisms. Hurford exemplifies the processes of cultural transmission by reference to research on grammaticalization (see also Tomasello, Chapter 6). Grammaticalization refers to rapid historical processes by which loose and redundantly organized utterance combinations can become transformed into a more compact syntactic construction (e.g. *My dad . . . He plays tennis . . . He plays with his colleagues* may become *My dad plays tennis with his colleagues*). Additional work within the computational modelling of language evolution provides further illumination of the possible consequences of cultural transmission. Specifically, Hurford describes computer simulations in which simple but coordinated language systems emerge within populations of artificial agents through iterated learning across generations (this work is described in more detail in Kirby and Christiansen, Chapter 15).

This book is in many ways a testament to the many different disciplines that have become involved in the study of language evolution over the past decade. In Chapter 4, however, Frederick Newmeyer points to the surprising fact that researchers in linguistics—the study of language—have been slow to join the resurgence of interest in the evolution of language (see also Bickerton, Chapter 5). Part of the reason, he suggests, may be that linguists are not in agreement about how to characterize *what* evolved, and this complicates uncovering *how* it may have evolved. Another possible stumbling block appears to be one of the key dogmas in linguistics: uniformitarianism. Almost all linguists take it for granted that, in some important sense, all languages are equal. That is, there is no such thing as a 'primitive' language—the language of a nomadic tribe of hunter-gatherers is no less complex than the language spoken in an industrialized society. Newmeyer suggests that a more measured approach to uniformitarianism is needed because there may have been differences in the use of language across language evolution. For example, language may originally have been used as a tool for conceptualization rather than communication. Newmeyer concludes that a less rigid view of uniformitarianism, combined with a better understanding of the biological bases for language and how languages change over time, is likely to lead to an increasing number of linguists raising their voices among the chorus of language evolution researchers.

Derek Bickerton strikes a more worried tone in Chapter 5 when discussing the odd fact that few linguists appear to be interested in language evolution. He is concerned that many non-linguists are proposing theories based on simplified 'toy' examples that may be inconsistent with the facts about language as seen from the viewpoint of linguistics. Against this backdrop, he suggests that when approaching language from an evolutionary perspective it is important to look at language not as a unitary phenomenon, but as the coming together of three things: modality, symbols, and structure. He argues that a largely cultural emergence of symbolic representation combined with a biological adaptation of brain circuitry capable of encoding syntactic structure were the two distinct evolutionary sources that gave rise to human language. Only later would a preference for the spoken modality have evolved, and then entirely contingent on the prior existence of the symbolic and structural components of language. From this perspective, the evolutionary dissociation of symbols and structure are reflected in ape language studies, where learning of symbolic relations approaches a near-human level of performance but where only a limited grasp of syntax has been demonstrated. Bickerton concludes that a capacity for structural manipulations of symbols may be the key adaptation that gives us, but no other species, language in all its intricate complexity.

Whereas Bickerton stresses the importance of linguistics in understanding the evolution of language, Michael Tomasello emphasizes the role of psychology. Nonetheless, Tomasello, in Chapter 6, also shares the view that it was the separate evolution of capacities for using symbols and grammar (that is, syntactic structure) that distinguishes human communication from the communication of other primates. In contrast to Pinker and Bickerton, he suggests that there was no specific biological adaptation for linguistic communication. Rather, Tomasello argues that there was an adaptation for a broader kind of complex social cognition that enabled human culture and, as a special case of that, human symbolic communication. A crucial part of this adaptation was an evolved ability to recognize other individuals as intentional agents whose attention and behaviour could be shared and manipulated. The capacity for grammar subsequently developed, and became refined through processes of grammaticalization occurring across generations (see also Hurford, Chapter 3)—but with no additional biological adaptations. In support for this perspective, Tomasello reviews psychological data from the study of language development in young children and from comparisons with the linguistic, social, and mental capacities of non-human primates (see also Hauser and Fitch, Chapter 9). More generally, Tomasello sees the origin and emergence of language as merely one part in the much larger process of the evolution of human culture.

In Chapter 7, Terrence Deacon also places the human ability for complex symbolic communication at the centre of the evolution of language. Contrary to Tomasello, however, Deacon does not find that the many subpatterns of language structure that can be found across all the languages of the worlds—the so-called language universals—are products of cultural processes; neither does he think that they reflect a set of evolved innate constraints (a language-specific 'Universal Grammar') as proposed by Bickerton, Pinker, and others. Instead, drawing on research in philosophy and semiotics (the study of symbol systems), Deacon argues that they derive from a third kind of constraint originating from within the linguistic symbol system itself. Because of the complex relationships between words and what they refer to (as symbols), he suggests that semiotic constraints arise from within the symbol system when putting words together to form phrases and sentences. As an analogy, Deacon refers to mathematics. Although the mathematical concept of division has been around for millennia, it would seem incorrect to say that humans invented division. Rather, we would say that the concept was discovered. Indeed, we would expect that mathematical concepts, such as division, are so universal that they would be the same anywhere in the universe. As an example, Deacon points out that the SETI (Search for Extra-Terrestrial Intelligence) project transmits pulses counting out prime numbers into deep space with the idea that any alien beings would immediately recognize that these signals were generated by intelligent beings rather than by some natural astronomical source. Similarly, Deacon proposes that during the evolution of language humans have discovered the set of universal semiotic constraints. These constraints govern not only human language but also, by their very nature, any system of symbolic communication, terrestrial or otherwise.

Iain Davidson, too, focuses on the human use of symbols in Chapter 8, but this time illuminated from the viewpoint of archaeology. He argues that anatomical evidence from skeletal remains contributes little to the understanding of the evolution of language because of the difficulty in determining possible linguistic behaviours from fossilized bones (but see Lieberman, Chapter 14, for a different perspective). Instead Davidson points to the archeological record of artefacts because they may reveal something about the behaviour that produced them. In particular, analyses of ancient art objects provide evidence of symbol use dating back at least 70,000 years. To Davidson, these artefacts indicate sophisticated symbol use that incorporates two key features of language: open-ended productivity and the ability to use symbols to stand for things displaced in time and place. On the other hand, he notes that evidence of syntax has proved more elusive in the archaeological record. Like many of the other contributors, Davidson sees symbol use as the first crucial step toward modern human language, with syntax emerging through cultural learning processes that include grammaticalization and iterated learning across generations (see also Hurford, Tomasello, and Kirby and Christiansen, Chapters 3, 6, and 15).

The previous chapters have highlighted the use of symbols as a unique human ability. In Chapter 9, Marc Hauser and Tecumseh Fitch take a biologist's perspective on language evolution, advocating the use of a comparative method for exploring the various other components that make up the human language ability. They argue that studying animals, in particular non-human primates, is the only way to determine which components of language may be unique to humans and which may be shared with other species (see also Tomasello, Chapter 6, for a similar point). Hauser and Fitch review a wealth of data regarding the mechanisms underlying the production and perception of speech. When it comes to vocal production, they find very little that is unique to humans (but see Lieberman, Chapter 14, for a different perspective), except perhaps a much more powerful ability for combining individual sound units (phonemes and syllables) into larger ones (words and phrases). As for speech perception, the evidence suggests that the underlying mechanisms also are shared with other mammals. Moreover, Hauser and Fitch propose that the mechanisms underlying the production and perception of speech in modern humans did not evolve for their current purposes; rather, they evolved for other communicative or cognitive functions in a common ancestor to humans and chimpanzees. However, Hauser and Fitch share with Bickerton the suggestion that the fundamental difference between humans and non-human animals is the capacity to use recursive syntax—the ability to take units of language, such as words, and recombine them to produce an open-ended variety of meaningful expressions.

In Chapter 10, Michael Arbib outlines another language evolution perspective that is based on comparison with non-human primates, but with a focus on brain anatomy. He suggests that biological evolution resulted in a number of pre-adaptations leading to a language-ready brain (see also Hurford, in Chapter 3). One of the key pre-adaptations on this account is the evolution of a mirror system, providing a link between the production and perception of motor acts. The mirror system has been studied extensively in monkeys where it is found in an area of monkey cortex (F5) that is considered to be homologous to Broca's area in the human brain—an area that appears to play an important role in human language. Arbib suggests that the mirror system forms the evolutionary basis for a link between a sender of a message and the perceiver of that message. The same subset of neurons appears to be active in the mirror system both when generating a particular motor act and when observing others producing the very same motor act. Following the evolution of a unique human ability for complex imitation, Arbib proposes that language originated in a system of manual gestures, and only later evolved into a primarily spoken form. Finally, Arbib joins Hurford, Tomasello, and Davidson in arguing that syntax emerged as the result of subsequent cultural evolution.

Michael Corballis also sees language as originating with a system of manual gestures, but comes to this conclusion from the viewpoint of cognitive and evolutionary neuroscience. In Chapter 11 he reviews a broad range of data, including studies of language and communicative abilities in apes (see also Tomasello, Chapter 6), the skeletal remains and artefacts in the archeological record (see also Davidson, Chapter 8), and the language abilities of hearing, deaf, and language-impaired human populations (see also Pinker, Chapter 2). He argues that whereas non-human primates tend to gesture only when others are looking, their vocalizations are not necessarily directed at others—perhaps because of differences in voluntary control over gestures and vocalizations. Corballis suggests that one of the first steps in language evolution may have been the advent of bipedalism, which would have allowed the hands to be used for gestures instead of locomotion. He follows Pinker in pointing to a gradual evolution of a capacity for grammar, though Corballis maintains that language remained primarily gestural until relatively late in our evolutionary history. The shift from visual gestures to vocal ones would have been gradual, and he proposes that largely autonomous vocal language arose following a genetic mutation between 100,000 and 50,000 years ago.

The gestural theories of language origin as outlined by Arbib and Corballis are not without their critics. Robin Dunbar argues in Chapter 12 that the arguments in favour of a gestural origin of language are largely circumstantial. He moreover contends that gestural language suffers from two major disadvantages in comparison with spoken language: it requires direct line of sight, and it cannot be used at night. Instead, Dunbar proposes that language originated as a device for bonding in large social groups. He notes that grooming is the mechanism of choice among primates to bond social groups. However, human social groups tend to be too large for it to be possible for grooming to bond them effectively. Language, on this account, emerged as a form of grooming-at-a-distance, which is reflected in the large amount of time typically spent verbally 'servicing' social relationships. Dunbar sees the use of primate-like vocalizations in chorusing—a kind of communal singing—as a key intermediate step in the evolution of language. Once such cooperative use of vocalizations was in place, grammar could then emerge through processes of natural selection. Like Pinker, Dunbar also refers to recent mathematical game theory modelling of language evolution in support of this standard Darwinian perspective (for details see Komarova and Nowak, Chapter 17). In addition, he points to the extraordinary capacity of language to diversify into new dialects and distinct languages, suggesting that this property of language may have evolved to make it easier for members of social groups to identify each other. Thus, Dunbar's proposal about the social origin of language can explain both the origin and subsequent diversification of language.

In Chapter 13, Michael Studdert-Kennedy and Louis Goldstein also point to vocalization as the basis for language evolution, but focus on the mechanics involved in producing the sounds of human languages. They propose that a key pre-adaptation for language was the evolution of a system in which a limited set of discrete elements could be combined into an unlimited number of different larger units (see also Hauser and Fitch, Chapter 9, for a similar perspective). They suggest that the ability for vocal language draws on ancient mammalian oral capacities for sucking, licking, chewing, and swallowing. Subsequent evolutionary pressures for more intelligible information exchanges through vocalizations would then have led to a further differentiation of the vocal tract. On their account, this resulted in the evolution of six different brain-controlled motor systems to modify the configuration of the vocal tract, comprising the lips, tongue tip, tongue body, tongue root, velum (the soft part in the back of the roof of the mouth), and the larynx (the 'voice box' containing the vocal cords). Different configurations of these discrete systems result in different phonetic gestures (not to be confused with the manual gestures mentioned by Arbib and Corballis, Chapters 10 and 11). Studdert-Kennedy and Goldstein argue that subsequent expansion, elaboration, and combination of phonetic gestures into larger complex structures would have occurred through processes of cultural evolution involving attunement among speakers through vocal mimicry.

In Chapter 14 Philip Lieberman, too, emphasizes the importance of speech production in language evolution. He reviews a wide range of neuropsychological and neurophysiological data relevant to explaining the evolution of language. Like Corballis, he points to the advent of bipedalism as the first step toward the evolution of language. However, Lieberman argues that upright walking would have resulted in biological adaptations of basal ganglia—a collection of subcortical brain structures—for the learning and sequencing of more complex movements. These changes to basal ganglia formed the key adaptation en route to language. In support for this connection between language and basal ganglia, Lieberman discusses a range of different language impairments, including impairments following strokes (aphasia), Parkinson's disease, and disordered language development—all of which appear to involve damage to basal ganglia. A consequence of this view is that language has a rather long evolutionary history, with simple symbol use (in the form of naming) and rudimentary syntax dating back to some of the earliest hominids. Lieberman notes, however, that modern speech would have emerged considerably later in human evolution, given his interpretation of the fossil record and comparisons with the vocalization abilities of extant apes. He argues that speech production may thus be the crucial factor that differentiates human and non-human primate communication (but see Hauser and Fitch, Chapter 9, for a different perspective).

Lieberman and Corballis both point to the evolution of more complex sequential learning and processing abilities as forming part of the foundation for the origin of language. In the first part of Chapter 15, Simon Kirby and Morten Christiansen similarly relate general properties of sequential learning to the structure of language. Specifically, they propose that many language universals—that is, invariant sub-patterns of language—may derive from underlying constraints on the way we learn and process sequential structure, rather than from an innate biological adaptation for grammar (see Pinker, Bickerton, Dunbar, and Briscoe, Chapters 2, 5, 12, and 16). Kirby and Christiansen present evidence from computational simulations and psychological experiments involving the learning of simple artificial languages, indicating that specific language universals can be explained by sequential learning constraints. This perspective further suggests that languages themselves can be viewed as evolving systems, adapting to the innate constraints of the human learning and processing mechanisms. Kirby and Christiansen report on computational modelling work in which coordinated communication systems emerge among groups of artificial agents through a process of iterated learning over many generations (also described by Hurford, Chapter 3). They argue that the broader consequences of this work are that language evolution must be understood through processes that work on three different, but partially overlapping timescales: the individual timescale (through learning in development), the cultural timescale (through iterated learning across generations), and the biological timescale (through natural selection of the species).

Whereas Kirby and Christiansen approach language evolution by investigating how the properties of cultural transmission across generations may affect language structure, Ted Briscoe focuses on the possible emergence of biological adaptations for grammar. In Chapter 16, he suggests that we may be able to understand how language-specific learning biases could have arisen in our evolutionary history by exploring how learning itself may impact on the ability to procreate. The assumption is that aspects of language, which were previously learned, would gradually become genetically encoded through 'genetic assimilation'—that is, through genetic adaptations for language selected to increase reproductive fitness (see also Pinker, Chapter 2, for a similar theoretical perspective). Based on a discussion of computational models of language acquisition, Briscoe contends that innate language-specific constraints are required in order to account for the full complexity of grammatical acquisition. Given this characterization of our current language ability, he argues that the only plausible way such innate constraints could have evolved in humans is through genetic assimilation. On this account, language started out relying on general-purpose learning mechanisms, but through biological adaptations learning gradually became language-specific. As support, Briscoe reviews a series of computational simulations in which grammatical assimilation emerges in populations of language-learning agents. In contrast, the simulations described in Kirby and Christiansen show how the task to be learned—in this case, language—may itself be shaped by the learner.

This volume concludes with Natalia Komarova and Martin Nowak who study language evolution from the viewpoint of mathematical game theory.[2] In Chapter 17 they first argue, on the basis of evidence from formal language theory, that innate constraints on language acquisition are a logical necessity. Komarova and Nowak note, however, that these results do not determine whether such innate constraints must be linguistic in nature—in fact, they could equally well derive from more general cognitive constraints—they only demonstrate that innate constraints on learning are needed. The formal language work is combined with an evolutionary approach based on game theory in order to provide a general mathematical framework for exploring the evolution of language. Within this framework language evolution can be studied in terms of populations of language-learning agents whose survival and ability to procreate depend on their capacity for language. The results indicate that natural selection would tend to favour systematic mechanisms for encoding grammatical knowledge. Such a system, for example, could be instantiated in terms of recursive rules, though any system capable of generating an infinite number of sentences would suffice. Although this research does directly address the question of whether evolved constraints would have to be language-specific or not, others have taken it to support the idea of a biological adaptation for language (see e.g. Pinker and Dunbar, Chapters 2 and 12). Komarova and Nowak's modelling work, together with that of Kirby and Christiansen and of Briscoe, demonstrates how mathematical and computational modelling can be fruitfully applied to the study of language evolution.

Consensus and Remaining Controversies

The chapters in this book provide a comprehensive survey of the state of the art in language evolution research. Many different disciplines are represented, and many different perspectives are expressed. Here, we seek to draw out the major points of consensus as well as the remaining controversies.

Possibly the strongest point of consensus is the notion that to fully understand language evolution, it must be approached simultaneously from many

[2] As editors, we realize that the chapter by Komarova and Nowak may appear daunting because of its mathematical content. However, we note that it is possible to gain a perfectly good grasp of the underlying ideas put forward in this chapter without necessarily understanding the maths behind them.

disciplines. This would certainly seem to be a necessary condition for language evolution research, in order to provide sufficient constraints on theorizing to make it a legitimate scientific inquiry. Nonetheless, most researchers in language evolution only cover parts of the relevant data, perhaps for the reason that it is nearly impossible to be a specialist in all the relevant fields. Still, as a whole, the field—as exemplified in this book—is definitely moving in the direction of becoming more interdisciplinary. Collaborations between researchers in different fields with a stake in language evolution may be a way in which this tendency could be strengthened even further.

Another area of consensus is the growing interest in using mathematical and computational modelling to explore issues relevant for understanding the origin and evolution of language. More than half of the chapters in this book were in some way informed by modelling results (though see Bickerton, Chapter 5, for cautionary remarks). Models are useful because they allow researchers to test particular theories about the mechanisms underlying the evolution of language. Given the number of different factors that may potentially influence language evolution, our intuitions about their complex interactions are often limited. It is exactly in these circumstances, when multiple processes have to be considered together, that modelling becomes a useful—and perhaps even necessary—tool. In this book, modelling work has been used to inform theories about biological adaptations for grammar (Pinker, Dunbar, Briscoe, Komarova and Nowak, Chapters 2, 12, 16, and 17), about the emergence of language structure through cultural transmission (Hurford, Deacon, Kirby and Christiansen, Chapters 3, 7, and 15), and about the evolution of phonetic gesture systems (Studdert-Kennedy and Goldstein, Chapter 13). We envisage that the interest in mathematical and computational modelling is likely to increase even further, especially as it becomes more sophisticated in terms of both psychological mechanisms and linguistic complexity.

There is a general consensus that to understand language evolution we need a good understanding of what language is. However, the field is divided over what the exact characterization of language should be, and in which terms it should be defined. Nonetheless, some agreement appears to be in sight regarding some of the necessary steps toward language. Specifically, there seems to be agreement that prior to the emergence of language some pre-adaptations occurred in the hominid lineage. There is less agreement about what these may have been, but one candidate that seems to be put forward by many is the ability for using symbols. Most also see grammatical structure as emerging during a later stage in language evolution, though opinions differ as to whether this was a consequence of an evolved innate grammar (Pinker, Bickerton, Dunbar, Briscoe, and Komarova and Nowak, Chapters 2, 5, 12, 16, and 17) or the emergence of grammar through cultural transmission (Hurford, Tomasello, Davidson, Arbib, and Kirby and Christiansen, Chapters 3, 6, 8, 10, and 15).

Of course, several major points of disagreement still remain. We have already touched upon the disagreement over whether constraints on language structure as reflected in human language are a consequence of biological adaptations for grammar or products of using and transmitting language across generations of learners with certain limited capacities. Another debated issue is whether language originated in manual gestures or evolved exclusively in the vocal domain. Although mathematical and computational modelling may help inform the discussions about how language came to have the structure it has today, it is less likely to be able to address issues related to language origin. However, evidence from other disciplines such as archaeology, comparative neuroanatomy, and cognitive neuroscience may provide clues.

One line of evidence that is likely to figure more prominently in future discussions of language evolution is results from the study of the human genome. A better understanding of the genetic bases of language and cognition, as well as its interaction with the environment, may provide strong constraints on language evolution theories, in particular with respect to issues related to the origin of language. Currently, however, the evidence appears to provide few constraints on such theorizing. In this book, Pinker, Corballis, and Lieberman (Chapters 2, 11, and 14) each cite data regarding the newly discovered FOXP2 gene in support for their theories of language evolution—even though the theories differ substantially. However, they do seem to agree that the FOXP2 data suggest a late evolution of speech. Therefore, the genetic data may be particularly useful for our understanding of the timeline for language evolution.

The Hardest Problem?

Understanding the evolution of language is a hard problem, but is it really the hardest problem in science, as we have provocatively suggested in the title of this chapter? This question is difficult to answer. Certainly, other scientific fields have their own intrinsic obstacles; those studying consciousness have already laid claim to the phrase 'the hard problem'. Nevertheless, it is worth considering the unique challenges that face language evolution researchers. Language itself is rather difficult to define, existing as it does both as transitory utterances that leave no trace and as patterns of neural connectivity in the natural world's most complex brains. It is never stationary, changing over time and within populations which themselves are dynamic. It is infinitely flexible and (almost) universally present. It is by far the most complex behaviour we know of—the mammoth efforts of twentieth-century language research across a multitude of disciplines only serve to remind us just how much about language we still have to discover.

There are good reasons to suppose that we will not be able to account for the evolution of language without taking into account all the various systems that underlie it. This means that we can no longer afford to ignore the research on language in fields other than our own. Understanding the origin of human uniqueness is a worthy goal for twenty-first-century science. It may not be the hardest problem; but we hope that this book will help us focus on the challenges ahead and go some way to showing what a complete theory of language evolution will look like.

FURTHER READING

The article (and associated peer commentaries) that gave rise to the resurgence of interest in language evolution, Pinker and Bloom (1990), may be a good starting point—when combined with this book—for looking at how the field has progressed over the last dozen years. The large volume of proceedings papers resulting from the 1975 conference sponsored by the New York Academy of Sciences on the origins and evolution of language and speech (Harnad et al. 1976) provides a good snapshot of the field a quarter of a century ago. It also contains an interesting paper by Hans Aarsleff on the history of language origin and evolution theories since the Renaissance.

A very good source of semi-technical papers covering a wide variety of topics and angles on language evolution can be found in the volumes based on selected presentations at the biennial conference on language evolution. So far, volumes have appeared from the 1996 conference in Edinburgh (Hurford et al. 1998), the 1998 conference in London (Knight 2000) and the 2000 conference in Paris (Wray 2002).

Cangelosi and Parisi (2002) provide a useful introduction to the modelling of language evolution—including chapters covering many different approaches to simulating the origin and evolution of language. For a competent and intelligible introduction to the issues relating to understanding the possible genetic bases for language, see Tomblin (in press).