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New Frontiers in Language Evolution and Development

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Abstract

This article introduces the Special Issue and its focus on research in language evolution with emphasis on theory as well as computational and robotic modeling. A key theme is based on the growth of evolutionary developmental biology or evo-devo. The Special Issue consists of 13 articles organized in two sections: A) Theoretical foundations and B) Modeling and simulation studies. All the papers are interdisciplinary in nature, encompassing work in biological and linguistic foundations for the study of language evolution as well as a variety of computational and robotic modeling efforts shedding light on how language may be developed and may have evolved.

Keywords: Evolution of language; Evo-devo; Developmental systems

Background to this issue

The work represented here is focused on interdisciplinary research in language evolution with emphasis on theory as well as computational and robotic modeling. A key theme is based on the fact that evolution and development of language are increasingly viewed as inherently related. This trend is partly due to growing scientific awareness of evolutionary developmental biology or evo-devo (see e.g., Carroll, 2005; Laland et al., 2015; West-Eberhard, 2003), a realm of study that emphasizes the idea that no structure or capability can be evolved without being developed, and that consequently, the targets of natural selection are often, if not usually, developmental processes or systems. The evo-devo theme is founded on pioneering work suggesting that (a) genes typically do not produce organismal form or behavior directly, but rather respond in cascades to products of regulatory genes that themselves respond to environmental stimuli, both internal and

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external (Müller & Newman, 2003); (b) development of both organismal form and behavioral capabilities occurs through dynamically varying cycles of interaction among levels such as protein-coding genes, regulatory genes, cells, brain/body, and culture (Gottlieb, 2007; Oyama, 2000); and (c) there are multiple avenues of inheritance beyond genetic mechanisms, including culture, learning, prenatal environment, and epigenetic factors (e.g., histone modification). Such research promotes a view in which genes cannot be equated to traits, but rather participate in a rich developmental process by which traits and behaviors emerge, in turn affecting gene expression and participating in multiple routes to inheritance.

While such approaches have been developed most extensively in animal models of organismal form, a number of recent efforts have begun to apply these approaches to behavioral evolution and development, including language and cognition (Bertossa, 2011; Spencer et al., 2009), often employing connectionist modeling (Christiansen & Chater, 2008; McMurray, Horst, & Samuelson, 2012), as well as drawing on dynamical systems (Thelen & Smith, 1994) and neuroconstructivist (Westermann et al., 2007) theories (cf. McClelland et al., 2010). The work encompasses fields as diverse as *genetics*, with increasing probes into foundations of language (Dediu, 2011); *linguistics* and *psycholinguistics*, with growing focus on roles for culture and how language change and structure can respond to and shape developmental process (Dale & Lupyan, 2012; Lupyan & Dale, 2010; Wedel, 2007); *robotics,* where ongoing interactions between robots and the physical and social world provide a powerful analogy to children's learning (Oudeyer & Kaplan, 2006); and cross-species work, illustrating mechanisms for learning of foundational language-like capabilities (Griebel & Oller, 2012; Pepperberg, 2010; Tomasello & Call, 2007). All these contribute to understanding the chains of epigenesis. Modeling can play a crucial role in this approach by illustrating non-obvious contributors to development (and by implication to evolution), along with non-obvious consequences of our theoretical commitments (Baronchelli, Gong, Puglisi, & Loreto, 2010; Christiansen & Chater, 2008; McMurray, 2007; Westermann et al., 2007).

All the papers in the Special Issue thus address one or more of the following: (a) under-recognized but critical foundations of language in terms of units, levels, and structures, as well as interactive environments of language; (b) how modeling can help elaborate our understanding of the dynamic ties between inherent predispositions of the organism relevant to language and the development and evolution of these foundations in real or simulated contexts; and (c) how evolution can operate at multiple levels of the system simultaneously. There is no unanimity among the participants in the Special Issue on how best to approach individual research domains within the evolution of language. Indeed, evo-devo is best seen as a meta-theoretical framework that fosters debate and inquiry about particular chains of causality within language change.

The topic builds on influential prior work in language evolution (Hurford, Studdert-Kennedy, & Knight, 1998; Pinker & Bloom, 1990) by addressing roles for natural selection and epigenetics within a multi-leveled developmental system. Genetically influenced predispositions are surely at stake, but they are always modulated by the mechanisms of language acquisition and its functions in communication and culture (since these are

selected for). Evo-devo provides a frame for our efforts, but the questions of how language emerges are always empirical, requiring basic research in genetics, language structure, and development, involving all the influencing environmental factors, supplemented by converging and synergistic evidence that in some cases can only be supplied by modeling. Similarly, a comparative, cross-species perspective provides a fundamental basis for evaluating mechanisms of acquisition and their ability to produce the highly specialized, evolved human behavior of language. We thus see development and evolution as intrinsically interconnected, and work on one can fundamentally inform the other, thus making it possible for the developmental and learning sciences to offer profound new insights and to suggest important constraints on evolutionary speculations.

The authors for the Special Issue represent diverse fields relevant for such synergy. Crucially, all span multiple traditions, including computational modeling at the intersection of learning and language change (e.g., Dale, Loreto, Lupyan, Westermann, Winter, Wedel, Christiansen, Warlaumont); genetics focused on the structure of language (Dediu); cross-species animal behavior (Griebel, Pepperberg, Schoenemann, McMurray); robotics collaborating with cognitive developmental psychology (Oudeyer, Smith, Breazeal, Harris); roles for culture, paralinguistics, and multiple modalities in language and language change (Lupyan, Bergen, Dale, Gussenhoven, Christiansen, de Boer); and language development (McMurray, Smith, Oller).

The Special Issue is organized in two sections. The first section primarily addresses theoretical issues regarding biological and linguistic foundations for the study of language evolution. The second section presents a variety of computational and robotic modeling efforts shedding light on how language may be developed and may have evolved. All the papers emphasize the need for flexibility in our approach to language evolution research, a kind of flexibility that is implied by the evo-devo framework of thought, with its inherent emphasis on interactivity of endogenous predispositions for learning and the systematic experiences that feed them, yielding in the case of language evolution, a rich coevolutionary process.

Part A: Theoretical foundations

Dediu and Christiansen argue that any approach to language evolution must take into account the biological sciences, and especially, they argue, genetics and evolutionary theory, in order to take advantage of the increasingly rapid pace of advancement in these fields. Their paper updates us on some of the key findings and theoretical developments and provides examples that cast new light on controversies about the nature of language and its evolution. The paper brings home the point that with so much growth in empirical information relevant to the study of language evolution, it is important to be flexible and to avoid dogmatism as we proceed in developing a workable theory of language and its origins.

Dale, Kello, and Shoenemann take note of the focus in prior work on language origins upon language as a system requiring control of intricately sequenced structures, while prior work has not tended to focus on the similarly important fact that language is multi-

dimensionally structured. In fact, the authors observe, not only language, but human cognition in general has both multimodal and multiscale organization requiring us as linguistic beings to be adept in interweaving diverse information sources and multiple levels of structure. The idea of "synergies" is critical in the authors' view, and it suggests new research questions that may help clarify ways that language is, and evolved as, a multimodal, multidimensional integrated system.

Oller, Griebel, and Warlaumont argue that study in the evolution of language has tended to address relatively advanced structures such as well-formed syllables, phonemes, words, phrases, and sentences. And yet, the human infant begins life with none of these structures. The authors review evidence that long before such elaborate structures are available to infants, more basic, infrastructural capabilities emerge, capabilities that represent a break with the primate background, and form foundations without which subsequent progress toward language would not be possible. The authors further argue that modeling of the evolution of language should begin at a point suggested by the evo-devo framework, accounting for the emergence of the required precursors upon which language development and evolution are founded. They provide a sketch of a research agenda for the very near future.

McMurray proposes that selection pressure on linguistic communication operates on two quasi-independent timescales. First, evolution must provide children with necessary foundations for language acquisition. Second, *during* development, children have to communicate with incomplete systems, so they are required to use whatever information and/or strategies may serve communication. Optimal solutions to the real-time requirement of communication may interact with the necessities of language acquisition and may produce complex combinations of language use and processing. The paper presents two case studies showing that demands of real-time communication and language acquisition (in realms related to infant-directed speech and fast mapping of vocabulary) may be subtly different and may interact to yield a complex pattern of evo-devo for language.

Lupyan and Bergen address ways that language programs the mind, and how this tendency may shed important light on evolution and development of language. The authors argue that while other animals can be trained to do things, they do not show the capability to be "programmed," a capability that constitutes a leap in the way the human organism can learn, interact, and transmit knowledge. A key idea is the manipulation and transmission of embodied, sensorimotor representations that constitute foundational patterns of language—these representations themselves make it possible for the human mind to be more "programmable" than the minds of other animals, and they provide a basis for co-evolution of language and mind.

Gussenhoven addresses evolutionary roots of language in paralinguistic communication, where form-meaning relations have properties that are deeply rooted in "biological codes," while maintaining the possibility of fine-tuning by culture. In particular "intonational morphemes," while somewhat culturally variable, are heavily biased by biologically based paralinguistic codes. He addresses four such codes, all pertaining to the prosodic realm of language and heavily associated with control of the phonatory mechanism. It is noteworthy that human infants begin life with vocal developments in the phonatory domain, and it

seems likely that paralinguistic codes were the first realms in which humans broke from the primate background in evolving toward true linguistic capabilities.

In the final paper of the first section, Griebel, Pepperberg, and Oller outline the inherently evo-devo claim, based on considerable evidence, that non-humans can be enculturated through human-rearing to communicate with much more language-approximating behaviors than have ever been reported to occur in the wild. Animals from extremely diverse taxa have proven capable of simple vocabulary learning, word combination usage and comprehension, and in some cases even speech-like production. The fact that such learning has not been observed in the wild (at least not to nearly the extent that can occur with human enculturation) suggests that culture provides a structure that can link evolution and development. Even in the human case, the authors argue, language and culture appear to have co-evolved, and the very substance and structure of language depends on cultural learning in each generation.

Part B: Modeling and simulation studies

Westermann proposes an alternative to the two predominant approaches to language evolution modeling, the one assuming language to be an evolved biological system of rules along with a lexicon and contextual constraints, and the other being based on the connectionist assumption that language can be learned with little or no biological predisposition. He advances a third idea emphasizing experience-dependent structural development of brain circuits supporting language. He presents evidence based on an embodied neuroconstructivist neural network, where initial domain-general predispositions in the context of structured statistical input enable the development of functionally specialized brain structures to manage the English past tense. These emerge then through interactions between experience-dependent brain development and statistical learning. The result of learning may appear to be two distinct mechanisms for processing rules and exceptions (as appears to occur in the adult English speaker), but the modeling shows the two subsystems can co-develop and interact closely. The work suggests processes and experiences that can lead to the interactive emergence of language capabilities.

de Boer presents a pair of computer simulations where agents evolve under selective pressure for imitation. One models the human vocal tract, and the other, a cognitive mechanism for perceiving speech. In both cases, adaptations to speech sounds evolve in the model extremely rapidly compared to the timescale of biological evolution. However, the model replicates the fact that the available acoustic space tends, in real languages, to be used maximally since the usage of the space is itself a self-organized result of cultural evolution. Thus, the acoustic space and the necessity of adapting to it is constant across the model and real language, illustrating that biological evolution has a stable target for its speech sound systems. The author interprets the models as showing that co-evolution of cultural and biological adaptations may yield patterns strong enough to detect empirically.

Loreto, Gravino, and Tria consider duality of patterning in language, which they characterize in terms of (a) a combinatorial level in which meaningless forms (phonemes or

syllables) are combined into meaningful forms (such as words) and (b) a compositional level where meaningful forms are composed into larger syntactic units. The authors introduce measures quantifying both combinatoriality and compositionality in a modeled language, and they present a framework to estimate these observables in natural languages. Second, they show that a multi-agent modeling scheme, the Blending Game, provides a framework in which a population of agents can bootstrap combinatoriality and compositionality. The predictions based on the model are in good agreement with empirical data.

Breazeal, Harris, DeSteno, Dickens, and Jong take on a fundamental question of how robotics may provide a key basis for testing language development and evolution theories by observation of interactions between real children and anthropomorphic robots. When their robots introduced their child participants to information about unfamiliar toys, the children treated the robots as interlocutors that were capable of providing information. The children proved especially attentive if a robot showed high non-verbal contingency, a pattern consistent with the way human children selectively seek information and attend to interlocutors that engage them effectively in various modalities. The work suggests paths toward further experimentation on development and evolution of language through interaction of real humans and robotic agents.

Oudeyer and Smith provide theory and data supporting the idea that language development and evolution require that learners be active, curious seekers of information and experience. They discuss mechanisms of endogenous exploration that yield self-organized epigenesis where ordered behavioral and cognitive developmental stages emerge naturally. Their robotic experiment explores the hypothesis that learning generates intrinsic rewards. The robots tended to select experiences that had the property of reducing uncertainty. In this way curiosity led the robots to discoveries, including ways they could interact with both objects and peers. The authors argue that the robot learning patterns mimicked those in infant development, and further, that these patterns can be seen as lying at the heart of possible evolutionary patterns, in particular regarding the origin of language.

Winter and Wedel model the range of variation in sound categories of language and illustrate that the range is constrained by functional pressure to maintain contrastivity. The method implements an agent-based exemplar model in which sound-category systems evolve in a co-evolutionary process where variation in sounds themselves is dynamically related to variations in their perceptual distinctiveness. The model is shown to reproduce empirically observed effects on sound variation in real languages. The authors argue that phonological systems seek a relative optimum of variation, wherein communication must be maintained, but wherein hidden category variation is also required to provide a basis for future evolution.

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KLI's workshops have previously resulted in numerous volumes published in the Vienna Series in Theoretical Biology (see e.g., Caporael, Griesemer, & Wimsatt, 2013; Müller & Newman, 2003; Oller & Griebel, 2008). The editors of the Special Issue of topiCS were also authors of papers in the Special Issue, and for those three articles, the editing was independently managed by Wayne Gray, the head editor of topiCS. Oller's work on this introduction was supported in addition to KLI, by the Plough Foundation and by a grant from the National Institutes of Health NIDCD R01 DC011027.

References

Baronchelli, A., Gong, T., Puglisi, A., & Loreto, V. (2010). Modeling the emergence of universality in color naming patterns. *Proceedings of the National Academy of Sciences*, *107*(6), 2403–2407. doi:10.1073/pnas.0908533107

Bertossa, R. C. (2011). Theme issue "Evolutionary developmental biology (evo-devo) and behaviour": Papers of a Theme issue compiled and edited by Rinaldo C. Bertossa. *Philosophical Transactions of the Royal Society B*, *366*(1574), 2055–2180. doi:10.1098/rstb.2011.0035

Caporael, L. R., Griesemer, J. R., & Wimsatt, W. C. (Eds.) (2013). *Developing scaffolds in evolution, culture, and cognition*. Cambridge, MA: MIT Press.

Carroll, S. B. (2005). *Endless forms most beautiful: The new science of evo devo and the making of the animal kingdom*. New York: W. W. Norton.

Christiansen, M. H., & Chater, N. (2008). Language as shaped by the brain. *Behavioral and Brain Sciences*, *31*(05), 489–509. doi:10.1017/S0140525X08004998

Dale, R., & Lupyan, G. (2012). Understanding the origins of morphological diversity: The linguistic niche hypothesis. *Advances in Complex Systems*, *15*(3 & 4), 1–16. doi:10.1142/S0219525911500172

Dediu, D. (2011). Are languages really independent from genes? If not, what would a genetic bias affecting language diversity look like? *Human Biology*, *83*, 279–296.

Gottlieb, G. (2007). Probabilistic epigenesis. *Developmental Science*, *10*(1), 1–11.

Griebel, U., & Oller, D. K. (2012). Vocabulary learning in a Yorkshire Terrier: Slow mapping of spoken words. *PLoS ONE*, *7*(2), 1–10. doi:10.1371/journal.pone.0030182

Hurford, J. R., Studdert-Kennedy, M., & Knight, C. (1998). *Approaches to the evolution of language*. Cambridge, UK: Cambridge University Press.

Laland, K. N., Uller, T., Feldman, M. W., Sterelny, K., Müller, G. B., Moczek, A., Jablonka, E., & Odling-Smee, J. (2015). The extended evolutionary synthesis: Its structure, assumptions and predictions. *Proceedings of the Royal Society B*, *282*, 20151019. doi:10.1098/rspb.2015.1019

Lupyan, G., & Dale, R. (2010). Language structure is partly determined by social structure. *PLoS ONE*, *5*(1), 1–10.

McClelland, J. L., Botvinick, M. M., Noelle, D. C., Plaut, D. C., Rogers, T. T., Seidenberg, M. S., & Smith, L. B. (2010). Letting structure emerge: Connectionist and dynamical systems approaches to cognition. *Trends in Cognitive Sciences*, *14*(8), 348–356.

McMurray, B. (2007). Defusing the childhood vocabulary explosion. *Science*, *317*(5838), 631.

McMurray, B., Horst, J. S., & Samuelson, L. (2012). Word learning emerges from the interaction of online referent selection and slow associative learning. *Psychological Review*, *119*(4), 831–877.

Müller, G. B., & Newman, S. A. (2003). *Origination of organismal form: Beyond the gene in developmental and evolutionary biology*. Cambridge, MA: MIT Press.

Oller, D. K., & Griebel, U. (Eds.) (2008). *Evolution of communicative flexibility: Complexity, creativity, and adaptability in human and animal communication*. Cambridge, MA: MIT Press.

Oudeyer, P.-Y., & Kaplan, F. (2006). Discovering communication. *Connection Science*, *18*(2), 189–206.

Oyama, S. (2000). *The ontogeny of information: Developmental systems and evolution* (2nd ed., rev. and expanded). Durham, NC: Duke University Press.

Pepperberg, I. M. (2010). Vocal learning in grey parrots: A brief review of perception, production, and cross-species comparisons. *Brain & Language*, *115*, 81–91.

Pinker, S., & Bloom, P. (1990). Natural language and natural selection. *Behavioral and Brain Sciences*, *13*, 707–726.

Spencer, J., Blumberg, M., McMurray, B., Robinson, S. R., Samuelson, L., & Tomblin, J. B. (2009). Short arms and talking eggs: Why we should no longer abide the nativist-empiricist debate. *Child Development Perspectives*, *3*(2), 79–87.

Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action*. Cambridge, MA: MIT Press.

Tomasello, M., & Call, J. (2007). *The gestural communication of monkeys and apes*. Mahwah, NJ: Lawrence Erlbaum Associates.

Wedel, A. (2007). Feedback and regularity in the lexicon. *Phonology*, *24*, 147–185.

West-Eberhard, M.-J. (2003). *Developmental plasticity and evolution*. New York: Oxford University Press.

Westermann, G., Mareschal, D., Johnson, M. H., Sirois, S., Spratling, M. W., & Thomas, M. S. C. (2007). Neuroconstructivism. *Developmental Science*, *10*(1), 75–83.

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