Language Sciences 62 (2017) 91–123

Contents lists available at ScienceDirect

Language Sciences

journal homepage: www.elsevier.com/locate/langsci

Language and other complex behaviors: Unifying characteristics, computational models, neural mechanisms

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ARTICLE INFO

Article history:
Received 14 January 2017
Received in revised form 4 April 2017
Accepted 7 April 2017

ABSTRACT

Similar to other complex behaviors, language is dynamic, social, multimodal, patterned, and purposive, its purpose being to promote desirable actions or thoughts in others and self (Edelman, 2017b). An analysis of the functional characteristics shared by complex sequential behaviors suggests that they all present a common overarching computational problem: dynamically controlled constrained navigation in concrete or abstract situation spaces. With this conceptual framework in mind, I compare and contrast computational models of language and evaluate their potential for explaining linguistic behavior and for elucidating the brain mechanisms that support it.

1. Introduction

How do brains compute language? The current consensus view in cognitive sciences, forty years after Marr and Poggio (1977) (cf. Marr, 1982; Poggio, 2012; Edelman, 2012), is that questions of cognitive computations and mechanisms cannot be settled without also addressing the other, complementary levels of understanding. Notably, there is the abstract or problem level: what is it, in terms of computation, that needs to be done, and why? Even this, methodologically more appropriate approach is, however, liable to lead nowhere if the problem-level hypotheses are mistaken, without being recognized as such—as seems to be the case both in Marr's original field, vision, which is still widely and erroneously believed to hinge on "object recognition" (Edelman, 2017a), and in language, where problem-level thinking is dominated by the conception of communication as packaging meanings into messages and by the tripartite dogma of grammar, sentence, and well-formedness (Edelman, 2017b; more about this in a moment).

A remedy for this methodological impasse is to augment Marr's three levels (problem, algorithm, and implementation) with two additional and related perspectives on the phenomenon in question, which are obligatory in biology: Mayr's (1961) concerns about explaining causation (including the distinction between proximate and ultimate causes), and Tinbergen's (1963) four questions—survival value, ontogeny (development), evolution, and behavioral causation. In language science, in particular, it is critically important to make questions of evolution, development, and behavior an integral part of the inquiry, as suggested next.

1.1. Language: postulates and reality

The reigning conceptual framework in linguistics, which underlies both the formalist and the functionalist theoretical outlooks,[1] rests on two postulates. First, with regard to the form or structure of language, it is held that the theoretical focus

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[1] For a book-length treatment of the distinction between formalist and functionalist linguistics, see (Newmeyer, 1998).

http://dx.doi.org/10.1016/j.langsci.2017.04.003
0388-0001/

should be on sentences, whose well-formedness is underwritten by a set of formal rules, or grammar. Second, the function of language is believed to be communication, construed as an exchange of "meanings"—information packets that are fully formed by the speaker, to be shipped to and decoded by the listener.

As I argued at some length elsewhere (Edelman, 2017b), it is time for these two postulates to be traded off for a biologically better motivated, and perhaps more promising, approach. To that end, we should consider both the form and the function of language—and perforce the computational processes that comprise it and the brain mechanisms that implement those processes—in a broader evolutionary and behavioral context. Specifically, the extensive literature on animal signals (e.g. Smith, 1965; Green and Marler, 1979; Macedonia and Evans, 1993; Lachmann et al., 2001; Seyfarth and Cheney, 2003; Ouattara et al., 2010; Kershenbaum et al., 2016) suggests that meaning in animal behavior in general and in language in particular should be conceived of not as a completed product to be "communicated" but as an open-ended interactive process to participate in—meaning-making—which is dynamically constrained by a range of factors that include the participants' shared social background, personal history, and immediate environment (Neuman, 2006; Stolk et al., 2016). ***The goal of this process, and the overarching use of language, is to influence behavior*** (Edelman, 2017b, section 6.2).[2] Likewise, the structures—composite actions or strands of behavior—that mediate this influence need not be computed completely ahead of time or syntactically well-formed; rather, linguistic behavior, just like any other complex sequential behavior, must be controlled flexibly and dynamically, subject to just enough constraints to make a difference in the desired direction (LaPolla, 2015; Edelman, 2017b).

1.2. A plan for this paper

In light of the above considerations, and in accordance with the research program outlined in (Edelman, 2017b), in this paper I adopt a pluralist stance that views language not as a peculiar faculty with a unique and evolutionarily unprecedented core function and brain substrate, but rather as a cluster of adaptations that supervene on neurocomputational systems which have analogs in other species and which jointly facilitate a range of behavioral tasks.

The notion that language as it exists in humans co-evolved with major systems of traits and functions, many of them shared with other taxa, has implications for understanding both its computational nature and its brain basis. On the task and computational levels, it motivates a search for commonalities between language and other behaviors (Kolodny and Edelman, 2015), such as navigation and foraging, which would imply that the problem of language is closely related computationally to the dynamical control of behavior (Bullock, 2004; Cisek, 2012). On the level of brain mechanisms, this approach shuns the standard corticocentric dogma in favor of a broad consideration of neural mechanisms that underlie action selection (Bullock et al., 2009) and sociality (Syal and Finlay, 2010).

My main goals in this paper are (i) to establish functional parallels between language and other complex behaviors; (ii) to evaluate and compare existing computational models of language, considered as a complex behavior; and (iii) to use this comparison to generate some insights into the brain basis of language. Accordingly, the paper is structured as follows. In section 2, I briefly review the types of behavioral tasks that exemplify what might be termed the generalized problem of behavior; section 3 then casts language as an instance of this problem. In preparation for assessing possible modeling solutions to it, in section 4 I list a set of criteria for neurocomputational plausibility, and state the explanatory goals that a good model must meet. These are then used to group computational models of language by algorithmic approach and to rank them by plausibility and explanatory power. Section 4 ends with a synthesis intended to serve as a basis for developing a new computational approach to language. In section 5, I briefly review the literature on the brain mechanisms of language and other sequential behaviors, focusing on the signatures of the proposed computational approach. Finally, section 6 offers a summary and a concise prognosis.

2. Language and other behaviors

Because understanding the structure or form of any evolved system depends on understanding of its function—a standard notion in biology in general (Bock and von Wahlert, 1965), as well as in language (Lenneberg, 1967; LaPolla, 2015)—I begin by briefly discussing some of the key categories of language use by humans.

2.1. The uses of language

A widely held view in linguistics is that the primary use of language is communication (e.g., Pinker and Jackendoff, 2005).[3] This view is, however, both misleading, insofar as it promotes the construal of linguistic communication as an exchange of coded "meanings" (as noted in section 1.1), and superficial, as it glosses over the many categories of use that humans make of

[2] Similarly, Anderson (2016) writes that "Language works by presenting and manipulating cultural affordances that will cause one's dialog partner(s) to see and do what the speaker intends to be seen and done." Importantly, although this claim revolves around *behavior*, which virtually necessitates mentioning (Skinner, 1957), it is anything but "behaviorist," as explained in Edelman (2017b).

[3] See Edelman (2017b) for more references and for a comparison of this essentially functionalist view with the one held by the formalists (e.g., Everaert et al., 2015), according to which language is primarily a tool for structured thinking, communication being merely its "ancillary" function.