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To Bilingualism and Beyond! Modeling Bilingualism Requires Looking Beyond Language: A Commentary on "Computational Modeling of Bilingual Language Learning: Current Models and Future Directions"

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Language is a symbolic system, and, like other symbolic systems (computer languages, math), it lends itself well to expansion, both within and across systems. Human minds can accommodate multiple symbolic systems simultaneously: They can understand a natural language, perform arithmetic, read musical notes, and perform a variety of tasks in which symbols are used (Marian, 2023).

In that sense, the multilingual language system does not possess a unique cognitive architecture that is categorically different, but rather multilingualism

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is the prototypical state of the human mind. When computational models of multilingualism go beyond existing monolingual language models, they frequently do so by focusing on how to differentiate the different languages, whether to represent them in integrated or separate ways, and how to control their use during input and output. There are multiple solutions for addressing each of these problems, but framing the questions around these issues may be missing the bigger picture, one in which language(s) cannot be separated from other mental phenomena.

A word's lexical form is tightly connected to its semantic representational features as well as to perceptual information, to memory, to affect, to other non-modular mental states. Form overlap across words guides not only recognition within the language system, but also the visual perception of the surrounding scene (Marian & Spivey, 2003), cognitive control (Blumenfeld & Marian, 2011), attention processes more generally (Chabal & Marian, 2015), and even long-term memory (Marian et al., 2021). These rich connections and interactions among cognitive functions are also found in neuroscience. The brain is not modular; instead, a broad whole-brain network is involved in processing symbolic systems, including the two languages of a bilingual, a network that emerges and continuously organizes itself with every new incoming piece of information.

Reviews of computational models of language in bilinguals are in agreement that language learning is a dynamic, interactive, developmental process whose study requires an interdisciplinary approach. Li and Xu's most recent review in this vein considers a range of models, covering Bayesian modeling, multimodal learning, and network science modeling, and can serve as an introductory primer for students and novices in the field who are not familiar with individual models or previous reviews of this area. It reflects the field's overall focus on prioritizing language learning, while also discussing models of visual word recognition, like BIA, BIA+, and Multilink, the development of which shaped the field. Computational models of bilingual spoken language processing, like the Bilingual Language Interaction Network for Comprehension of Speech (Shook & Marian, 2013), are rarer, but just as necessary.

Existing models, however, focus on distinct individual aspects of language, such as learning, visual processing, auditory comprehension, or translation, rather than on a broad integrated framework that can accommodate the full spectrum of tasks managed by the bilingual cognitive network. The limitations of such separate models underscore the need for computational accounts of bilingualism to shift from discrete models focused on separate tasks to larger integrated models that more accurately reflect human language.

Those who model bilingualism agree that interdisciplinary approaches building on knowledge from computational neuroscience, natural language processing, and first language acquisition are needed to move the field forward. However, formulating precisely how that should happen is more difficult.

One thing that is clear, however, is that the computer metaphor the authors alluded to is no longer appropriate. To wit, the computer is a poor metaphor for the human mind. It dates to the 1950s and was relatively popular in the decades that followed, but it no longer reflects modern understanding of neuroscience, computer science, and cognitive science more broadly. The sooner researchers abandon the mind-as-a-computer lens, the sooner it will be possible to advance computational modeling of the mind, including the bilingual mind, beyond the constraints of a computer metaphor.

To understand bilingualism and to model it successfully, modeling efforts need to move away from considering language in isolation and to instead integrate it into a broader cognitive framework. Bilingualism is not just about language, although that is its most immediately salient component and the one those who study bilingualism tend to focus on. Bilingualism also shapes perception, memory, learning, emotion, decision making, and other functions. Successful modeling of bilingualism requires the recognition of a broader cognitive network in constant flux, where symbolic systems impact the entire cognitive architecture of the human mind.

Much about modeling language learning in bilinguals is not specific to bilingualism nor even to language learning, but applies more broadly to learning in general. What exactly is specific to language, and what is specific to bilingualism or multilingualism, if anything, is an open question. Asking and answering these broader questions is likely to hold the key to the next generation of computational models of bilingualism.

The field of bilingualism stands on the precipice of the next big shift in computational modeling of multiple languages, but exactly how to cross it is less clear. As modelers look around trying to figure out how to "solve" the problem of modeling bilingualism, the solution will need to extend beyond two languages, to cognitive functions more broadly.

The task may seem overwhelming; accomplishing it will be no small feat indeed, but at this point the field is more ready for it than ever before. Modern computing capabilities are increasingly able to accommodate massive amounts of data and to handle ambitious modeling efforts. The last few decades have seen smaller individual problems being worked out within the modeling of perception, comprehension, reading, learning, memory, and other domains. Although putting the different pieces of the puzzle together is a daunting task, the zeitgeist is right for it. Even if the full picture does not reveal itself at once, and we can only start by combining a few pieces at a time in an incremental manner (like perception and language, or language and memory—note that none of these are distinct categories!), a fuller picture will begin to emerge over time.

Ultimately, modeling bilingualism means moving beyond modeling the learning of two languages to modeling the brain's capacity for multiple symbolic systems, a defining feature of the human mind.

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