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Introduction to the 2007 Rumelhart Prize Special Issue Honoring Jeff Elman

Language is a hallmark of human cognition, and the study of language reveals fundamental insights into what makes us uniquely human. It is therefore no surprise that three of the seven Rumelhart Prize winners thus far are scholars of language science (the two previous winners, Aravind Joshi and Paul Smolensky, are both computational linguists). Jeff Elman's significant contributions to the language sciences, though they exist on many fronts, is perhaps most elegantly captured by his view of ''Language as a Dynamical System,'' a title from Elman's 1995 article, and a theme running through the presentations at the 2007 Rumelhart Symposium that formed the basis of this Special Issue.

Elman's early training was in experimental phonetics, an area of research that was hugely important to the parallel distributed processing (PDP) enterprise in the development of connectionist models of language. With Jay McClelland he created the TRACE model, the first large-scale interactive activation model of speech perception, which led to one of the pivotal chapters on language in the PDP volumes (McClelland & Elman, 1986). TRACE implemented mechanisms that provided a framework for detailed investigations into how the auditory signal unfolds in the perceptual context, and it relied on dynamic interactions across levels of acoustic features, phonemes, and words to capture processes of phonemic identification and spoken word recognition. Compared with other important models at the time (e.g., COHORT), TRACE was able to perform better under noise conditions, for example, by using higher-order knowledge of the lexicon to parse lower-order sequences of phonemes into words and establish word boundaries. Properties and behaviors of the TRACE model were highly consistent with empirical facts about speech, and the model ignited intense debates concerning the cognitive and perceptual mechanisms underlying speech perception, up to this day.

Perhaps Elman's most influential scientific achievement was marked, his 1990 paper, ''Finding Structure in Time,'' a now classic text of the *Cognitive Science* journal, and indeed, of the entire cognitive science field (*Google Scholar* shows a citation of well over 3,000 for the article). In this article, Elman provided a central premise of the language-as-dynamical-system perspective, that is, that structured representations such as those of linguistic categories, taxonomies, hierarchies, or even recursion can emerge from the dynamic interactions of the learner with the learning environment. Language unfolds in time, and the perception and acquisition of language cannot be understood without a clear understanding of the temporal dynamics involved in the relevant cognitive and perceptual

processes. In particular, Elman proposed the simple recurrent network (SRN) to model the temporal dynamics in learning through the recurrent connections from the hidden units to the context units, of which the latter serve as a dynamic memory buffer for temporal information processing. Learning in the SRN involves the prediction task, in which the network receives streams of words in the unfolding input and attempts to predict what word will occur next given what has occurred up to the point. The SRN provides a simple but powerful mechanism to identify structural constraints in the linguistic input, allowing for the emergence of linguistic categories without having recourse to prescriptive, a priori entities in the mental representation. Clearly, SRN follows TRACE as another example *par excellence* of the dynamical perspective on language.

While the SRN's scientific influence reaches afar to areas such as artificial neural networks, computer science, and engineering, the next landmark work by Elman and his colleagues, *Rethinking Innateness*, has had a deep impact on all of the developmental sciences. Elman, Bates, Johnson, Karmiloff-Smith, Parisi, and Plunkett (1996) and Plunkett and Elman (1997) published the two-volume set that synthesized insights from connectionist modeling and developmental neurobiology, in which they illustrated how we could study ontogenetic development within the connectionist perspective. Hailed by some as the second cognitive Bible following the PDP volumes in 1986, *Rethinking Innateness* takes hard developmental issues head on, by suggesting that once we look at the interactive dynamics underlying development from a connectionist perspective, the nature versus nurture dichotomy becomes less meaningful. Specifically, Elman and colleagues suggested that we rethink innateness and its role at three different levels, representational innateness, architectural innateness, and the timing of maturational events. Previous considerations of innateness had mainly focused on the first level, including most nativist views of language. By rejecting representational innateness and embracing connectionist mechanisms and constraints for brain development and learning, Elman and colleagues infused a new theoretical perspective into an age-old debate on the role of innateness versus environment in cognitive and linguistic development. This perspective, indeed, foreshadows many popular topics in today's developmental and cognitive sciences with respect to learning dynamics and neural plasticity.

Howard Gardner once said that great thinkers tend to turn to new ways of thinking every 10 years. In Elman's case, we have already seen three waves of new thinking within the 1986–1996 period. If that were not enough, his recent ''words-as-cues'' hypothesis, an alternative view of the mental lexicon (see Elman, 2009), is sure to invite a new round of discussion on the nature of linguistic representation. In 2004, Elman published in *Trends in Cognitive Science* an Opinion piece, arguing that it is the ''mental states,'' the contexts in which the lexical entries occur and interact, that define what words really are. This idea contrasts further with traditional linguistic views that a mental lexical entry contains a fixed representation of phonological, semantic, and grammatical information relevant to the construction of phrases and sentences, in and of themselves, stored in the long-term memory of the speaker and accessed during speaking or listening. For Elman, the contingent contexts that define the meanings of words can be both linguistic and nonlinguistic, and these contexts serve as cues for the inclusion of relevant features in the representation, often on the

fly during language processing. In essence, Elman argues for the existence of lexical knowledge without a lexicon.

In addition to these landmark pieces of scholarly work, Elman has also been instrumental in building language science as a vibrant subfield of cognitive science. He was the founding director of the Center for Research in Language (CRL) at the University of Californias San Diego (UCSD), and together with the late Elizabeth Bates, they made CRL one of the most active centers of connectionist psycholinguistic research. Elman also served as Chair of the UCSD Cognitive Science Department (1995–1998), and as President of the Cognitive Science Society (1999–2000). He is currently Chancellor's Associates Endowed Chair, Distinguished Professor of Cognitive Science, Co-Director of the Kavli Institute for Brain and Mind, and Dean of the Division of Social Sciences at UCSD. In all contexts, Jeff's generosity, his modest character, along with his intellectual sincerity, compassion, and wit, deeply impress and affect colleagues who have interacted with him. His exemplary scholarship, leadership, and citizenship are contagious and are inspiring to even those who have not worked with him.

In this Special Issue, close colleagues of Jeff Elman (former students, collaborators, friends) and Elman himself, describe how the dynamical perspective has influenced our thinking about the relationships among language, cognition, culture, and the brain. First, Elman provides an extended view of his ''words-as-cues'' perspective on the mental lexicon, drawing parallels between the processing of word meanings and the understanding of prehistoric relics (drawing on some insights of David Rumelhart). The remaining chapters deal with how language acquisition, comprehension, and representation can be examined and understood as emergent properties in learning and processing environments. Gerry Altmann and Jelena Mirkovic describe a variety of data demonstrating how incrementality in language comprehension is intimately tied to dynamically changing predictions with respect to what is likely to be coming next, addressing the relationship between prediction, event structure, thematic role assignment, and incrementality. Mary Hare, Ken McRae, and Jeff Elman present empirical data that demonstrate robust structural anticipation effects, suggesting, instead of the existence of encapsulated syntactic stages, early interactions between meaning and structures during on-line sentence comprehension. Ping Li discusses the computational and neural mechanisms underlying lexical organization, structural representation, and competition within and between languages in the acquisition and processing of native and nonnative languages, drawing data from both connectionist modeling and functional neuroimaging. Christopher O'Connor, George Cree, and Ken McRae focus on emergent conceptual hierarchies and the temporal dynamics of similarity, showing that an attractor network can produce emergent behavior consistent with human performance previously thought to require a hierarchical architecture. Finally, Valentina Gliozzi, Julian Mayor, Jon-Fan Hu, and Kim Plunkett provide behavioral and computational evidence on the role of labels in category formation during infancy, suggesting that labels may override the manner in which infants categorize objects even before infants start to produce their first words. Together, these papers weave the various topics and approaches into one general theme that has been championed by Jeff Elman and his colleagues: language as a dynamical system.

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