Cognitive Network Science: Quantitatively Investigating the Complexity of Cognition

Yoed N. Kenett* (yoedk@sas.upenn.edu)
Department of Psychology, University of Pennsylvania
Philadelphia, PA 19104 USA
Nichol Castro (castro070503@gmail.com)
Department of Speech and Hearing Sciences, University of Washington
Seattle, WA 98195 USA
Elisabeth Karuza (ekaruza@psu.edu)
Department of Psychology, Pennsylvania State University
University Park, PA 16801 USA
Michael S. Vitevitch (mvitevit@ku.edu)
Department of Psychology, University of Kansas
Lawrence, KS 66045 USA
*** - Organizer**

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Cognition is complex. This complexity is related to multiple, distributed neurocognitive processes dynamically operating across parallel scales, resulting in cognitive processing. A major challenge in studying this complexity, relates to the abstractness of theoretical cognitive constructs, such as language, memory, or thinking in general. Such abstractness is operationalized, indirectly, via behavioral, measures or in neural activity. In the past two decades, an increasing number of studies have been applying network science methodologies across diverse scientific fields to study complex systems.

Network science is based on mathematical graph theory, providing quantitative methods to investigate complex systems as networks (Baronchelli, Ferrer-i-Cancho, Pastor-Satorras, Chater, & Christiansen, 2013; Siew, Wulff, Beckage, & Kenett, 2018). A network is comprised from nodes, that represent the basic unit of the system (e.g., concepts in semantic memory) and links, or edges, that signify the relations between them (e.g. semantic similarity). While the application of network science methodologies has become an extremely popular approach to study brain structure and function, it has been used to study cognitive phenomena to a much lesser extent. This, despite classic cognitive theory in language and memory being highly related to a network perspective (Collins & Loftus, 1975; Siew et al., 2018). Already, network science in cognitive science has enabled the direct examination of the theory that high creative individuals have a more flexible semantic memory structure, identified mechanisms of language development through preferential attachment, shed novel light on statistical learning, shown how specific semantic memory network parameters influence memory retrieval, and provided new insight on the structure of semantic network of second language in bilinguals (Siew et al., 2018).

The aim of the current symposia is to demonstrate the potential and strength of applying network science methodologies to study cognition. This will be achieved by bringing together leading researchers that apply such methods to study various aspects of cognition, including language, learning, aging, and creativity. The presentations will describe state-of-the-art progress and perspectives that are achieved in applying these methods to study cognition. Importantly, these talks aim at stimulating discussion of the fruitfulness of such an approach and how such an approach can powerfully and quantitatively study the complexity of cognitive phenomena. Finally, this symposium aims to demonstrate how network science in cognitive science can be used to quantitatively bridge across different levels of analysis, spanning the computational, behavioral, neural, and social.

Yoed Kenett: Introducing cognitive network science

In recent years, network science has become a popular tool in the study of structure and dynamics at the neural level of the brain. Despite its rich potential, this has been the case to a lesser extent to the study of cognitive phenomena. This, despite classic cognitive theory in domains such as memory and language being heavily based on a network perspective (Collins & Loftus, 1975; Siew et al., 2018). In this talk, I will argue for the potential of applying the quantitative language of networks to study cognition. I will first describe methodological approaches to estimate cognitive networks and relevant network science measures. I will then briefly describe how cognitive network research can be applied to study the structure, processes, and dynamics of cognitive domains. These examples will focus on semantic memory and relate to aspects of creativity, spreading activation, and semantic memory restructuring. Finally, I will argue that cognitive network science can be used to quantitatively bridge across multiple domains of analysis, spanning the neural, cognitive, and social.

Nichol Castro: Capturing the aging lexicon using network science techniques

Word findings problems increase with age, even in the absence of disease or impairment. Although some accounts attribute word finding problems to changes in domain general cognitive processes, the prominent explanation is a deficit in accessing phonology due to weakened connections between lexical items and their phonological constituents between lexical items and their phonological constituents (Burke, MacKay, Worthley, & Wade, 1991). In other words, there is a change in the structure of the mental lexicon that occurs with age. However, quantifying structural change in the mental lexicon has remained understudied. This talk will show how the tools of network science can be used to identify key structural changes in phonological and semantic networks occurring across adulthood (e.g., Dubossarsky, De Deyne, & Hills, 2017). A discussion of how structural change could impact language processing will ensue, followed by a brief foray into the implications of aging lexicon networks in clinical populations. In particular, it's important that we consider how aging impacts the lexicon of not just "healthy" adults, but also those who have suffered brain insult (e.g., in the case of stroke-induced aphasia).

Elisabeth Karuza: Probing the level at which learners track co-occurrence patterns

Humans are highly attuned to the clustering of elements in their surroundings. For example, when learners are confronted with novel sequential input, their element-by-element processing times have been shown to reflect the community structure (i.e., multi-element patterns of co-occurrence) underpinning those sequences. In this talk, I will detail recent developments in a framework for examining learners' sensitivity to the network structure of their environment. Prior applications of this framework have generally involved assigning a handful of unnatural stimuli (e.g., fractal images) to nodes in a small network and generating sequences by walking along its edges (Karuza, Kahn, Thompson-Schill, & Bassett, 2017; Schapiro, Rogers, Cordova, Turk-Browne, & Botvinick, 2013). Here, I will describe the expansion of this approach to encompass the study of larger temporal networks comprised of more naturalistic stimuli (e.g., manipulable objects and phonotactically legal pseudowords). Finally, I will examine how the collection of off-line measures might serve to clarify the previously observed relationship between on-line processing times and network architecture.

Michael Vitevitch: Connecting the MIND and the BRAIN with multiplex networks

Poeppel and Embick (2017) describe two problems researchers face when trying to bring together the mind and the brain: (1) granularity mismatch problem, and (2) ontological incommensurability problem. In the granularity mismatch problem, the elemental concepts and operations of Cognitive Science doesn't match the elemental concepts and operations of Neuroscience. In the ontological incommensurability problem, the fundamental elements of Cognitive Science cannot be reduced to or matched up with the fundamental biological units of neuroscience. Poeppel and Embick (2017) suggest that computational models may overcome these problems and provide the desired bridge between mind and brain. As an alternative to bridging the mind and brain, I discuss the possibility (and potential problems) of using multiplex networks to bridge mind to brain, and to bridge the individual mind-brain to the mind-brains of others.

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