Using Complex Network Analysis in the Cognitive Sciences

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Objectives and Scope of the Tutorial

- Provide an elementary introduction to network analysis as a tool within cognitive science, using examples from the domain of language.
- Demonstrate how to import, manipulate, and analyze network data using the R programming language.
- Participants who complete the tutorial will be able to perform basic network analyses, and use this powerful suite of analyses to examine relational data in their own domains of research.

Tutorial Delivery

The general format of the tutorial will be a half-day introduction to research in the field of complex network analysis followed by a more detailed study of a specific research project on language acquisition. In the course of the more detailed study participants will have an opportunity to perform some statistical and hypothesis testing on networks while learning interpretations and meaning of network analysis techniques.

We will begin by introducing a few research findings that are specific to network analysis. These include results showing that there are structural network differences that can be quantified and compared between groups as well as examples of conclusions that readily emerge from a networking framework that would otherwise be difficult to capture. These require a fundamental understanding of a variety of network descriptives that will be defined and applied to the research questions at hand. For example, in capturing and explaining structural network differences, we introduce the idea of clustering coefficients and geodesic distance. These network descriptives have become specifically relevant to the field, as they have given rise to the idea of small-world structure, which has been shown to allow for efficient processing and navigation of information. From there we introduce the idea that network statistics change with the size and density of a graph. That brings up concepts of randomization and statistical tests. While these will be handled initially as definitions and concepts, the second part of the tutorial will include working through the analyses that were conducted to yield the research results. We will conclude the tutorial by allowing participants to design their own hypothesis tests and help with refining individualized research goals in light of network theory. If time and interest permits we will also consider process models of networks, inference on missing data and missing link information as well as network-based algorithms.

We will teach participants how to do basic network calculations with built-in functions of R as well as help develop an intuitive understanding of network models. At the end of the session we will also introduce the idea of network process models specifically looking at preferential attachment and page rank algorithms.

Instructor experience with Network Analysis

Nicole Beckage is a graduate student majoring jointly in Cognitive Science and Computer Science at University of Colorado Boulder. Nicole has spent most of her course work and research focusing on network analysis and language acquisition. She has helped run network tutorials at the Institute of Social Network Analysis's annual conference and has taken many classes in a variety of disciplines with network theory as a main topic. Her research has utilized and designed novel network approaches and she has been invited to give network related talks at many workshops and conferences. The focus of the methodological tutorial will be motivated by the techniques of her paper entitled 'Small worlds and semantic network growth in typical and late talkers' published in *PLOS One* in 2011.

Michael Vitevitch is an Associate Professor in the Department of Psychology at the University of Kansas. Prof. Vitevitch combines the analytic tools of Network Science with conventional psycholinguistic tasks to better understand the processes and representations involved in spoken word recognition. His work in this area has appeared in several mainstream Psychology journals (e.g., *Cognitive Science, Journal of Memory & Language*, *Journal of Experimental Psychology: Human Perception & Performance*) as well as in journals that focus on the topics of chaotic, complex, and nonlinear systems (e.g., *Entropy*, and *International Journal of Bifurcation and Chaos*). In addition to organizing a satellite conference on the topic of "Language and Network Science" at the 2012 NetSci conference in Chicago, he has been invited to present his network research at a number of international workshops and conferences.

Alexander Mehler is professor for Computational Humanities at the Goethe University Frankfurt am Main, Germany, where he heads the Text technology Lab as part of the Department of Computer Science and Mathematics. He is a member of the executive committee of the LOEWE Priority Program "Digital Humanities" at Frankfurt University. His research interests include empirical analysis and simulative synthesis of discourse units in spoken and written communication. He aims at a quantitative theory of networking in linguistic systems to enable multi-agent simulations of life cycles. He integrates models of semantic spaces with simulation models of language evolution and topological models of network theory to capture the complexity of linguistic systems. He heads several research projects on the analysis of linguistic networks. His work has appeared in several journals in the area of computational linguistics, cognitive science and complex systems (Neural Networks, Journal of Quantitative Linguistics, Computer Speech and Language, Entropy, Applied Artificial Intelligence). In 2012, he organized a conference on Modeling Linguistic Networks based on which he will co-edit the first (Springer) volume on linguistic networks in cognitive science and related disciplines.

Eliana Colunga is an Associate Professor in the Departments of Psychology and Neuroscience and Computer Science and a Fellow of the Institute of Cognitive Science at the University of Colorado Boulder. Prof. Colunga studies interactions between language and cognition using cross-linguistic, developmental and computational modeling methods. Her work on computational models of language development has been published in journals such as Psychological Review, Cognition, Developmental Science, and has been funded by the John Merck Fund and the Eunice Kennedy Shriver National Institute of Child Health & Human Development of the National Institute of Health. She received her PhD in Computer Science and Cognitive Science from Indiana University and her MS in Artificial Intelligence and BS in Computer Science from the Instituto Tecnologico y de Estudios Superiores de Monterrey, Mexico.

Why Network Analysis at Cognitive Science?

Over the last few decades the work on network analysis has been revived and expanded with new analytical, numerical and theoretical approaches. It has become a fundamental force within a variety of fields from physics, computer science and psychology to sociology and political science. The types of questions many cognitive scientists ask, such as studying the structure of language, studying group dynamics or neuronal dynamics, can be framed within a network perspective and we hope by building a team of researchers who work with network analysis as their main framework we can excite others in the field to utilize these techniques. Further, utilizing a tutorial structure will allow for us not only to explain our research findings but also give others the tools they need in order to begin answering their own questions within this framework. With this in mind, we expect the audience of this tutorial to be interested in learning about network analysis for any purpose.

Likely Audience for the Tutorial

Because our expertise is mostly tied to language many participants may be interested specifically in language, but the application of this method extends beyond language. This tutorial is specifically useful for types of relational data. Though the material covered in this workshop will be relatively basic, we hope to give participants a flavor for the strength and power of network analysis techniques.

Special Requirements for the Tutorial

The participants will be asked to bring laptops to the meeting as well as have R and a few select libraries (statnet, sna package and network package) installed. A .zip file will be available with other necessary files for the completion of the tutorial material. By working through past research findings, participants will receive an overview of basic network functions in R and have the opportunity to perform cognitively meaningful network data manipulation. We will also introduce visualization techniques of network data. We perform statistical tests to understand the structure present in the observed network compared to what might happen under different conditions. This requires calculations of network descriptives (e.g., centrality scores, graph-level indices); and use of classical network analytic techniques and network specific statistical tests.

No prior experience with R is necessary and attendees do not need to have a familiarity with the basic concepts of descriptive network analysis.

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