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Can We Already Conceive of a Computational Construction Grammar That Is Adequate to Address the Data of Neurolinguistics?

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Abstract

This panel addresses the question: What are the brain mechanisms that support the use of language by modern humans? In particular, the aim is to understand the mechanisms linking perception, action, meaning and language. As an entry point into the study of grammar needed for this purpose, we have sought to bridge between brain theory (Arbib & Bonaiuto, 2016) and construction grammar. Unfortunately, even computational construction grammars come in diverse forms and so this raises the question: What can each version contribute to the eventual emergence of a Neural Construction Grammar (NCG) whose computations are linked to those for perception and action in a neurally plausible way to form an integrated model NCG++ of the larger system, and what gaps remain to be filled?

Structure of the Session

Arbib will present an overview of the challenges in neurolinguistics development of NCG++ must face.

The panelists will then present key points concerning the strengths and weaknesses *with respect to this development* of

- Dynamic Construction Grammar (DCG, Peter Ford Dominey)
- Embodied Construction Grammar (ECG, Nancy Chang)
- Fluid Construction Grammar (FCG, Michael Spranger) and
- Template Construction Grammar (TCG, Victor Barrès)

with due attention to how grammar links to interaction with the external world.

General Criteria

Neural construction grammar must be informed by neuroscience (e.g., by matching localization studies based on fMRI, on lesion studies, or comparative studies of primate brains, and ERP studies which reveal timing correlates such as the N400 and P600), and suggest new neuroscience experiments. It must have an adequate situation model to link with studies linking language to, e.g., visual input and motor output, linking to neuroscience data while also supporting robotics applications.

The ability to explain complex language processing using neural algorithms rooted in neuroscience data is crucial, as is explanation/prediction of information flow in the brain (integration with vision, motor control, social cognition). Motivating issues concern neural modeling of how language can be learned by human infants (ontogeny) and how language processing in individual brains changes as a function of interactions with other individuals in a linguistic culture, but these will be secondary for this panel.

The main difficulty is that language is a complex system. The foundational assumption of construction grammar is in fact that disparate aspects of linguistic form, meaning and context might all be combined in the same construction. Adding to that is our need to understand how these connect to perceptual, motor and other systems. Moreover, cognitive functions like inference, category formation, construal, memory, etc., can all play a role in particular instances of language understanding. Teasing out the correspondences of all these structures and functions to the brain may require rather more experimental sophistication than currently available.

Dynamic Construction Grammar

DCG is implemented as a simulation of cortical dynamics encoding sentence structure and striatal neurons that learn to “read out” semantic roles (Hinaut & Dominey, 2013; Hinaut, Petit, Pointeau, & Dominey, 2014). Those roles are most easily (computationally) represented in a predicate-argument form. Ideally, semantic roles should be represented in a more embodied representation of meaning that would include extended distributed semantic networks (Jouen et al., 2015). The different XCG systems address this problem (a symbolic to distributed-embodied interface) differently, and if we can make some progress on this point it will be a significant move forward.

DGC can partially fulfill the neuroscience requirement because it is based on the neurophysiology of the corticostriatal system and can explain how unpredicted events cause neural responses like the P600. The DCG situation model may be related to ECG schemas and TCG SemReps?

Embodied Construction Grammar

Broadly: ECG has been designed within the context of the broader Neural Theory of Language project, which has been integrating constraints from cognitive/linguistic phenomena at an intermediate level of abstraction.

In particular, the ECG formalism is expressive enough to supports phenomena running the gamut of linguistic complexity, both in terms of conceptual structure (spatial relations, motor control, event structure, conceptual metaphor) and grammatical domains (single words, argument structure, tense and aspect, morphology, speech act constructions).

ECG has a specific role within a model of simulation-based language understanding, serving as an interface between declarative linguistic knowledge and the dynamic structures that support action and perception in situated contexts. It is also the target for a usage-model of language acquisition that mirrors the developmental trajectory of child learning their earliest constructions.

The computational abstractions assumed by ECG are motivated by biological evidence (e.g. parameterized, hierarchical motor representations) and have principled reductions to structured connectionist models but the extent to which these can be mapped on existing neural structures remains unknown, and addressing this must be part of the work on NCG++.

Fluid Construction Grammar

Neural construction grammar must take into account the handling and processing of complex Natural language. It seems therefore reasonable to consider the insights that FCG has on handling linguistic phenomena (Steels, 2011) such as Aspect (Gerasymova et al. 2012), spatial language (Spranger, 2016), determiners (Pauw & Hilferty, 2012), event structure (Steels et al., 2012) to name a few. Relevant studies include proposals about handling complex linguistic phenomena using symbolic operations such as unification (matching and merging), planning, and search; a procedural semantics interface to vision and motor control (Spranger et al, 2012); and usage-based language learning based on incremental generalization of constructions (Gerasymova et al, 2012; Spranger, 2015).

Of special relevance are ideas about how to link such symbolic models to neural models (Knight et al, 2015) by translating symbolic operations into vector space models and, followed by automatic generation of spiking neuron models. The challenge here is that implementation in artificial neural networks does not guarantee matching the neurological data above, demanding “constraint satisfaction” to determine which aspects of FCG++ will carry over into NCG++.

Template Construction Grammar

TCG has a brain theory based implementation, employing schemas rather than neurons as the unit of computation. It preserves some the symbolic processes and representation still necessary to account for non-trivial linguistic behavior, while incorporating them within a framework in which each sub-system can potentially be refined as more empirical evidence is collected or as progress is made from the “bottom-up” and some specific functions can be implemented in neural networks.

TCG anchors language processes on vision for both production and comprehension (Barrès & Lee, 2014) which allows it to harness (for part in its implementation, for part in its contributions at a more conceptual level) the large body of neuro-cognitive knowledge on the visual system. As the grammatical processing core of the Schema-Architecture Language Vision InterAction model (SALVIA), TCG develops a theory of the vision-language interface. At the behavioral level, building on psycholinguistic levels, it explains some key results related to the observed relations between visuo-attentional scene parsing and the production of scene descriptions.

TCG incorporates both psycholinguistic and neurolinguistics data into the design of the model. Particular attention is placed on building a system that can be lesioned in order to be tested against key aphasia results, in particular the fact that Broca’s aphasia impacts both production and comprehension in related ways (agrammatic production and comprehension).

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References

Arbib, M. A., & Bonaiuto, J. J. (Eds.). (2016). *From Neuron to Cognition via Computational Neuroscience*. Cambridge, MA: The MIT Press.

Barrès, V., & Lee, J. Y. (2014). Template Construction Grammar: From Visual Scene Description to Language Comprehension and Agrammatism. *Neuroinformatics, 12*(1), 181-208.

Hinaut, X., & Dominey, P. F. (2013). Real-time parallel processing of grammatical structure in the fronto-striatal system: a recurrent network simulation study using reservoir computing. *PLoS One, 8*(2), 1-18. doi: 10.1371/journal.pone.0052946

Hinaut, X., Petit, M., Pointeau, G., & Dominey, P. F. (2014). Exploring the acquisition and production of grammatical constructions through human-robot interaction with echo state networks. *Front Neurorobot, 8*.

Jouen, A., Ellmore, T., Madden, C., Pallier, C., Dominey, P., & Ventre-Dominey, J. (2015). Beyond the word and image: characteristics of a common meaning system for language and vision revealed by functional and structural imaging. *NeuroImage, 106*, 72-85.