Predicting neural activity by modelling the nuts and bolts of language trees

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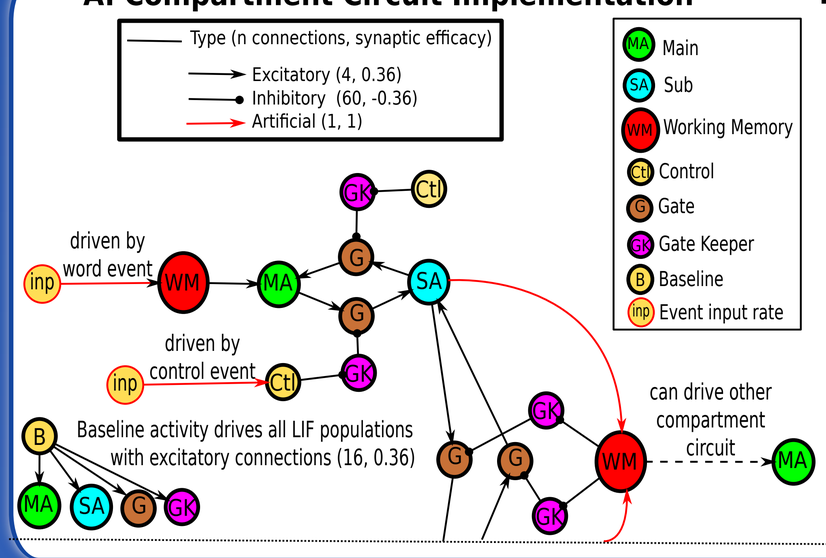
Abstract

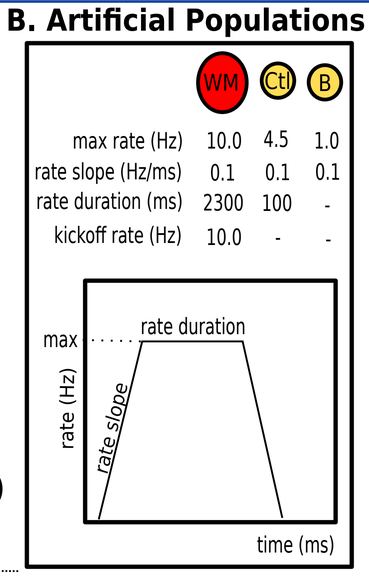
Few attempts have been made to model language in biological neural networks. The Neural Blackboard Architecture (NBA), proposed by Van der Velde and De Kamps [1] is one of them. It was designed to answer many challenges in the neural modeling of sentence processing, including the ones detailed by Jackendoff [2]. Here we expand on previous simulations of the Blackboard Architecture [3] on leaky-integrage-and-fire (LIF) populations with population density techniques [4] implemented in MIIND [5], to compare simulated time courses of neural activity associated to sentence representation and parsing with functional magnetic resonance data (fMRI) and intracranial recordings (electro-corticography; ECOG).

Neural Blackboard Architecture Implementation

A. Compartment Circuit Implementation

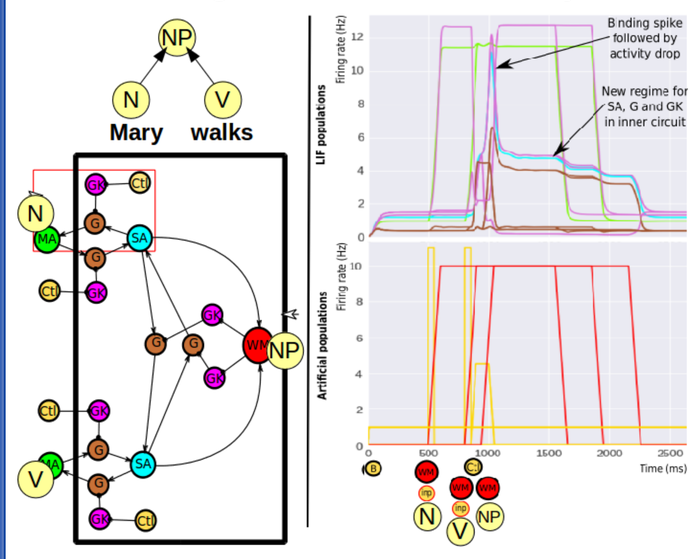


B. Artificial Populations



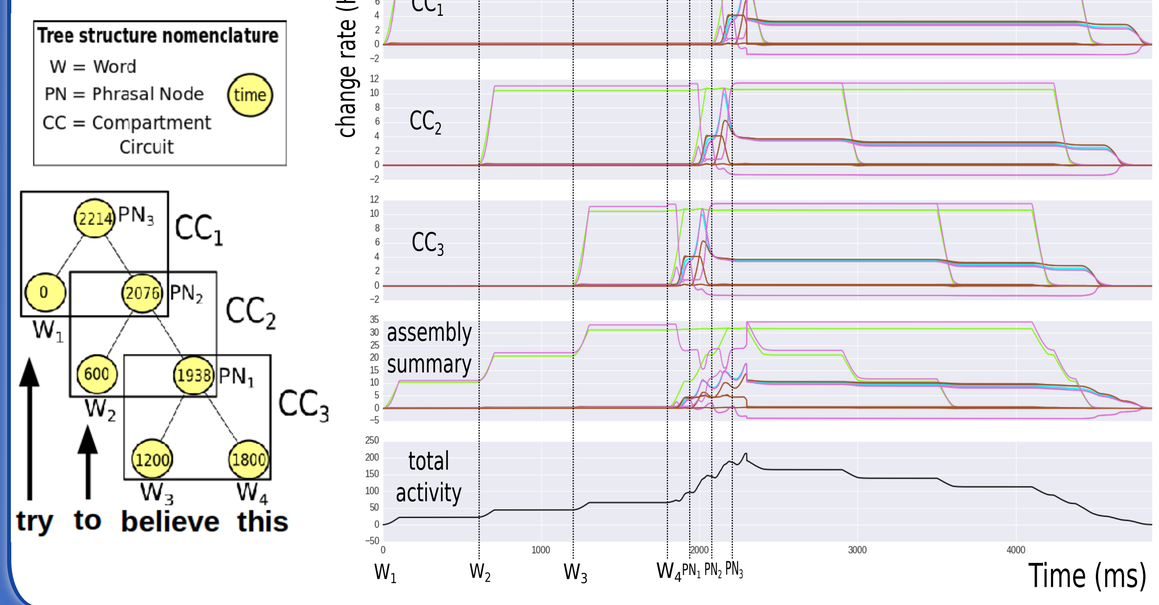
Each node in the compartment circuit (A), represents a LIF neural population, except for Working Memory, control and baseline that represent activity in reverberating artificial neural populations described by the function plotted in (B). The LIF model parameters were taken from Omurtag et al [6], baseline activity was determined from Wohrer et al [7] and synaptic efficacy was taken from Briggs et al [8].

Binding related neural activity



In case both MAs are active and Ctl activates to allow flow from MAs to their SAs, then binding will take place by activation of WM. Moreover other interesting non trivial dynamics take place. During the process of binding the reverberating activity of WM that inhibits the GKs connecting SAs creates a sudden burst of activity leading to a pronounced spike, this is due to the fact that SAs create a self excitatory loop, also elevating the activity of Gs and GKs between them. This burst of activity quickly drops back to a steady state that leaves the inner circuit in a level of activity far greater than in its original resting state, facilitating possible future communication between MAs.

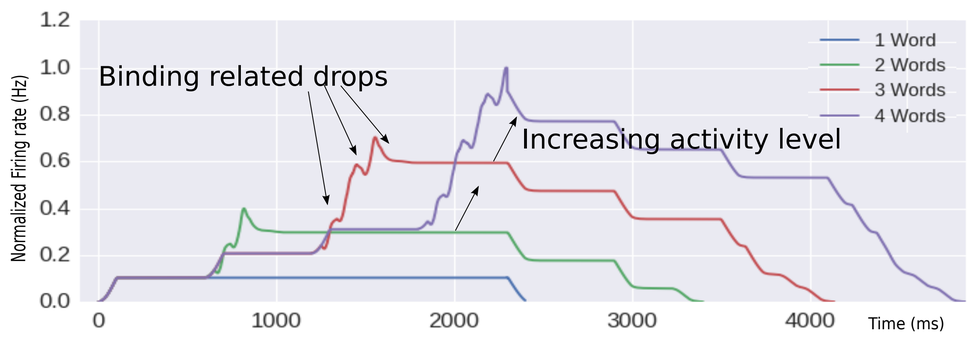
Right branched tree sentence for a phrase grammar with bottom-up parsing



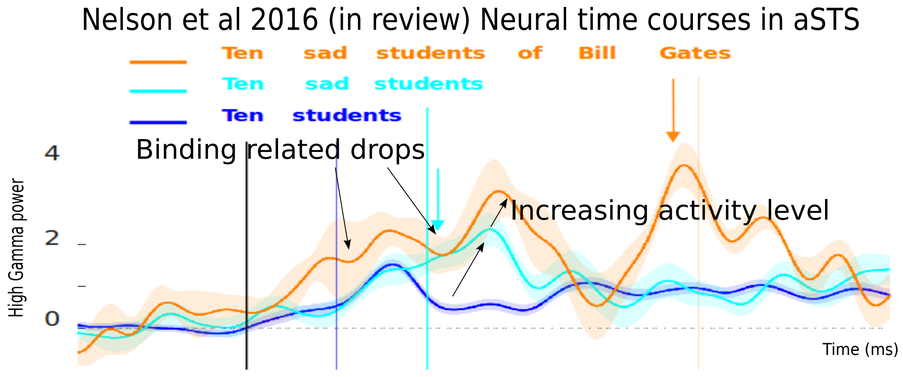
Tree structure hypothesized for a given 4 words phrase. It is shown how compartment circuits correspond to sections of the tree structure and how the nodes corresponding to grammatical categories of words processed or phrase nodes are instantiated in time under a bottom-up parsing scheme. The activity of the LIF populations of each compartment circuit are shown separately, followed by their summary and total activity.

Neuroimaging predictions

ECOG predictions from increasing size right branching trees

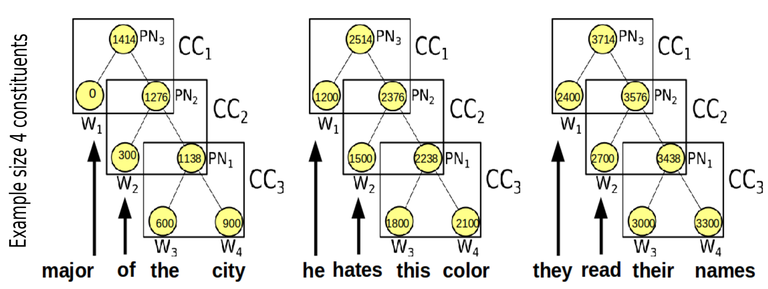


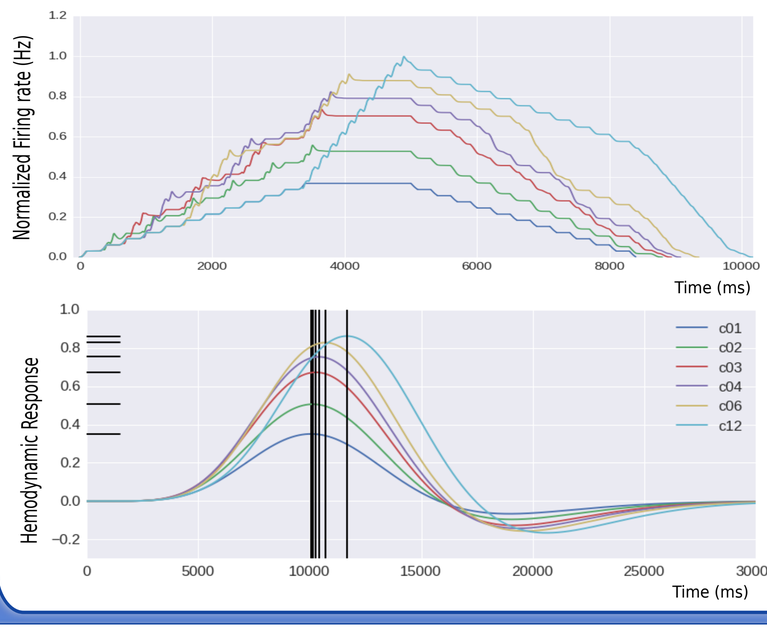
Nelson et al 2016 (in review) Neural time courses in aSTS



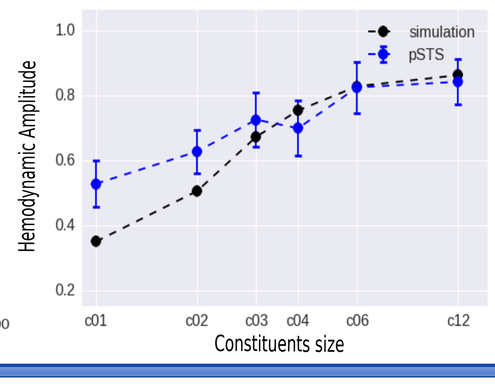
Nelson et al. (under review) [9], shows that Local Field Potentials increase with phrase constituent size and drop after binding of words into constituents. We observe both qualitative properties with a simulation of right branched phrases with increasing number of words.

fMRI predictions simulating varying constituent size as in Pallier et al. 2011





In a study of Pallier et al [10], about manipulation of the size of constituents in sequences of 12 words presented visually to participants, they observed a sublinear increase of the amplitude of hemodynamic responses in language related regions as a function of constituent size. We reproduce the pattern under a phrase grammar theory with a simple bottom-up parsing scheme.



What next?

We plan to extend the simulation to at least three parsing schemes: bottom-up, top-down and left corner. Then we will fit the nodes activity in the circuit and the timing of working memory nodes and controls to ECOG data in specific regions. The models fitted to specific regions will allow quantitive predictions on diverse fMRI dataset

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