Looking through a microscope through a telescope:
Dynamical systems, categories, and the misreading of Marr

Sam Tilsen
Cornell University (USA)

"What are the invariant physical correlates of abstract phonological categories?" – This talk will address the workshop topic from a dynamical systems perspective. I will argue that we should pursue the development of more complex, integrative, neurologically plausible models, as opposed to narrowly focused, parsimonious ones. A question I will tackle up front is: *What are we make of the notion of a "category" in theorical frameworks such as Task Dynamics?*

Very generally, our first job in a dynamical systems approach is to construct a state space, along with a change rule that tells us how the current system state changes from one moment to the next. The rest of the task, is the construction of the *tasks* [1]: we just have to figure out how to characterize and generate the trajectories in the state space that correspond to the patterns we observe in our data—the "categories". Phonological categories from this perspective may (or may not) correspond to sets of state space trajectories that bear similarities. A crucial observation is that some trajectories are visited more than others—explaining the emergence of these transient attractors is a worthwhile long-term goal.

But how should we go about pursuing this goal? I will discuss three general approaches:

The minimalistic approach. One option is to develop mathematically minimal models that can generate specific empirical patterns of interest [2]. Although such models are elegant in their simplicity, I argue (i) that they suffer from a lack of explanatory power and (ii) that they are not readily integrated with current understandings of nervous system dynamics.

The task dynamics approach. The fundamental assumption behind the construction of tasks (e.g. Saltzman & Munhall, 1989) is that we can usefully approximate our description of the system at lower levels via coarsegraining [4]. For example, we can effectively ignore the scale of muscle fiber bundles in our models of articulatory control because fiber bundle interactions are assumed to self-organize in a way that subserves a more simplified description on the scale of articulators. A common theme used to justify this sort of approach is the Marrian appeal to the usefulness of understanding the "computational level" of description of a system [5], [6]. Yet this logic is based on a highly selective reading of Marr, who (I will demonstrate) emphasized the need for integrative description across levels, i.e. across implementation, algorithm, and computation.

Neurally inspired dynamics. I will discuss three examples of models inspired by current knowledge of the nervous system. These models aim to be integrative in nature, and in fact, purport to be testable with anticipated improvements in our ability to observe the me-varying state of the nervous system.
(i) Based on the fact that there is a high-degree of somatotopy in primary motor and somatosensory cortices, and on the finding that the spatial targets of oculomotor and manual movements are spatially represented in such areas, it is likely articulatory targets have similar neural representations. This idea has formed the basis for dynamical field theories [7] and I have pursed the development of models along these lines (Figure A).
(ii) The fact that cortical and subcortical neural sub-populations are observed to enter into transient oscillatory states [8] provides motivation for coupled oscillator models [9], and I have pursued elaborations of such models that incorporate parameters reflecting the internal properties of neural ensembles (Figure B).
(iii) Findings that task sequencing appears to be governed by population activity codes [10] is consistent with competitive queuing models of motor control [11]. This inspired aspects of the selection-coordination theory of phonological organization [12]. In all three cases, I will show how the additional complexity of the models endows them with greater explanatory power than is provided by simpler, more abstract models.

In sum, this talk argues that in order to understand "categories" in a way that is consistent with the wide range of variation observed in empirical patterns, we need to develop more complex, biologically plausible models of speech behavior.

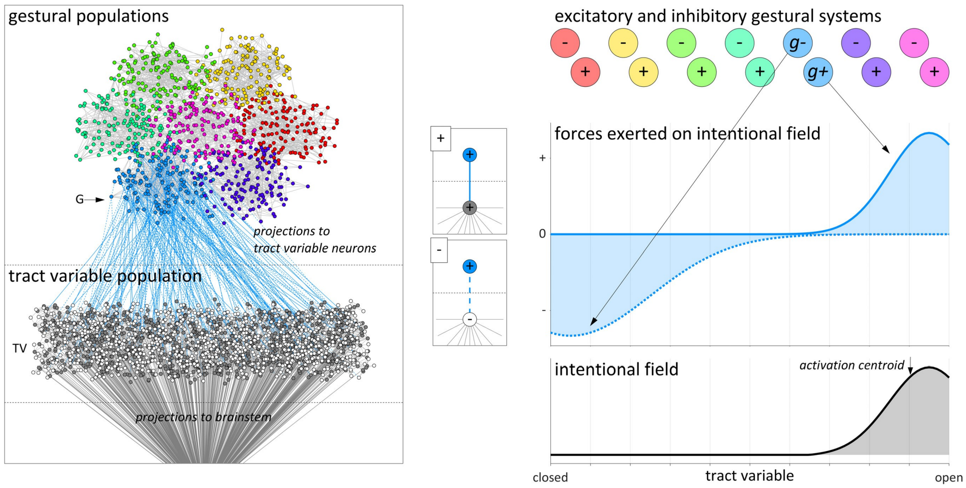

Figure A. (from [13]) Somatotopy of primary motor and somatosensory cortices provides a basis for dynamical field models of motor state control. This allows for a wider range of phonological patterns to be understood.

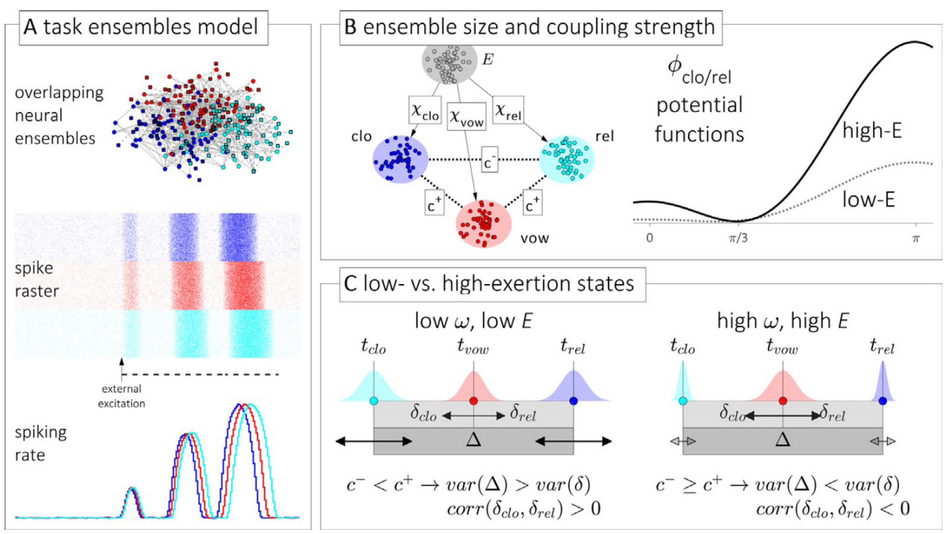

Figure B. (from [14]. Recognizing that cortical populations have finite sizes and are comprised of sub-populations of inhibitory and excitatory neurons introduces new parameters into coupled oscillator models, allowing for greater power to account for variation.

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