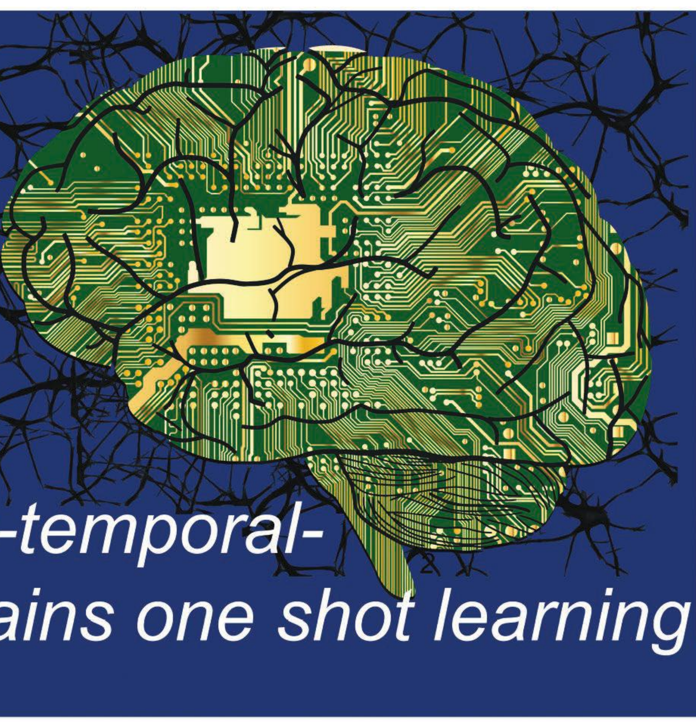
Fast mapping in the cortex



Samora Hunter, B.Sc
Supervised by Dr. Max Garagnani

Neurobiologically constrained perisylvian, fronto-temporal-occipital computational model of the cortex explains one shot learning

University of London
Goldsmiths College
Computational Cognitive Neuroscience M.sc

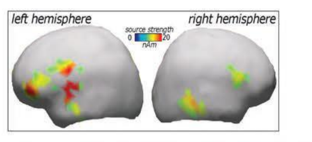
Abstract

Adult human beings typically possess a vast vocabulary that is notably absent at birth. As infants and adults, they demonstrate the capacity to learn new lexical items, more specifically, to map a word onto an external environment referent. Little research has been done to investigate the neural mechanisms underlying this ability, particularly regarding sub twenty minute acquisition of word meaning known as fast mapping. The present study addresses this literature gap. A procedure for simulating spontaneous cell assembly formation, in the context of word meaning acquisition, as a response to environmental stimulation was adapted from previous research[1]. It was deployed under a novel paradigm detailed below. This initial stage led to the spontaneous emergence of three region distinct cell assembly types, corresponding to assemblies' resultant from purely visual input, motor input or articulatory/phonological input. Subsequent presentation of the auditory component of the articulatory/phonological assembly and either visual or motor assembly presentations showed evidence of binding after just a few presentations. Following this we show that only simulated auditory input is sufficient to ignite this bound cell assembly. This assemblies extension linked articulatory/phonological representation of a word to its basic semantic grounding visual or motor representation.

3

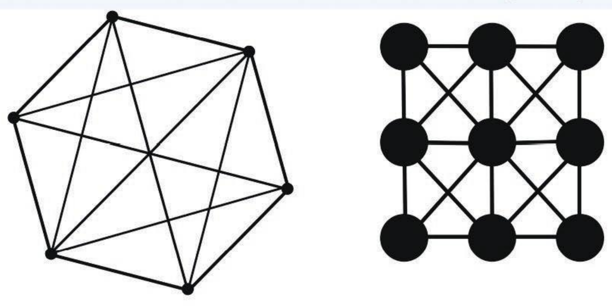
"..When an axon of cell A is near enough to excite cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A 's efficiency, as one of the cells firing B, is increased"

"Organization of Behavior: A Neuropsychological Theory" (1949).[4]

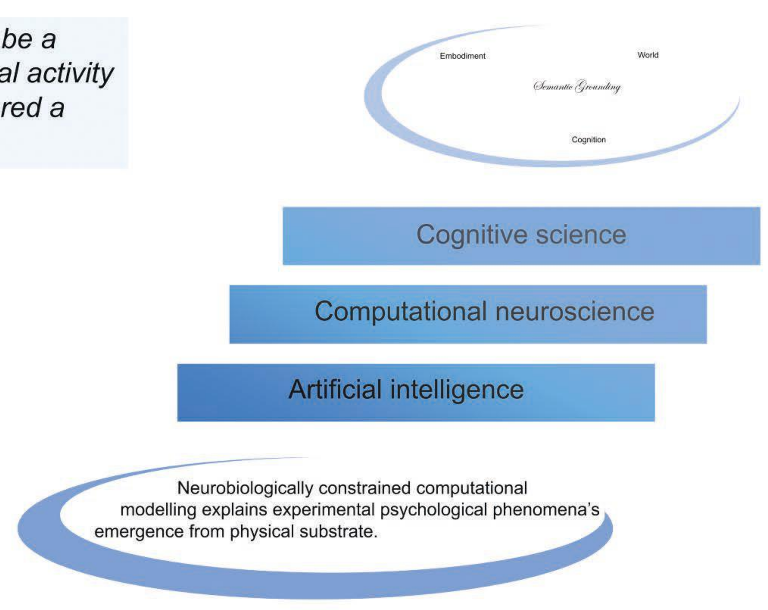


Fast mapping of novel word forms traced neurophysiologically, Shytrov, 2011)[5].
Brain response dynamics change dramatically within twenty minutes.

"...The cortical distributions of these assemblies must be a consequence of where in the cortex correlated neuronal activity occurred during learning. An assembly can be considered a functional unit...." ~Friedemann Pulvermüller (1999).[8]



V. Braitenberg proposed Hebbian cell assemblies as carriers of meaning.7



Background

- Developmental psychology has shown experimentally that children are capable of fast mapping lexical items onto their respective external environment referents[6].
- Neuroscientific investigations report rapid dynamic neurophysiological changes during word learning [5].
- Previous research has employed this model in the simulation of word acquisition and semantic grounding[1].

We simulate rapid word meaning acquisition with a neurobiologically and anatomically constrained computational model.

Materials

- Plasticity is simulated by adapted Hebbian learning principles (ABS rule).
- The model[1] consists of twelve areas, six Perisylvian and six Extraslyvian.
- Area connections are in line with known neuroanatomical links.
- Artificial cells constrained by randomised sparse connectivity, connectivity probabilisticially bounded by a local neighbourhood and modulated by an inhibitory mechanism.
- Each area contains 625 artificial excitatory and inhibitory cells, (15,000 total). Each artificial excitatory cell correspond to 25,000 real pyramidal cells in a cortical column. [1]
- Randomised activation input patterns corresponding to three visual object, three motor action and six pairs of articulatory/phonological representations per simulation.

B[1]

Schematics of micro connectivity of a single neurobiologically constrained cell.

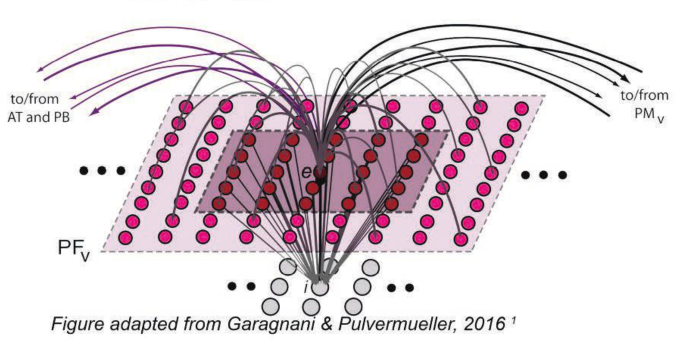
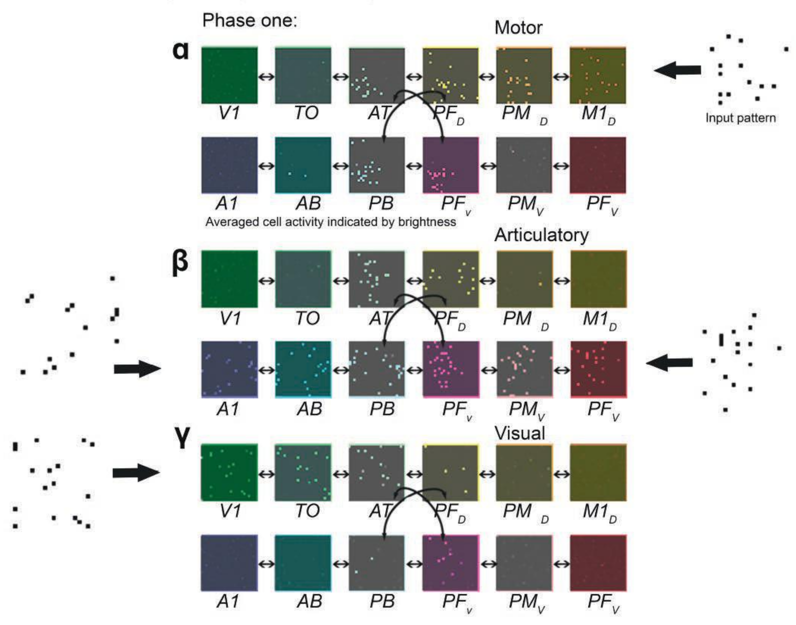


Figure adapted from Garagnani & Pulvermueller, 2016 [1]



A[1]

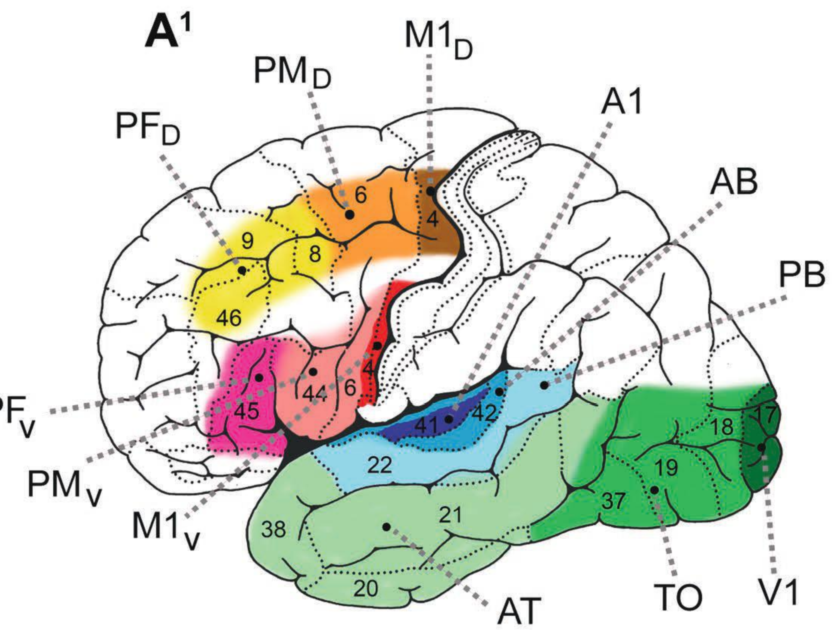


Figure adapted from Garagnani & Pulvermueller, 2016 [1]

Methods

The acquisition of a words meaning was simulated using an existing approach[1]: Basic word meaning is taken as requiring a link between the articulatory/phonological and either a visual representation of the object to which it corresponds, or a motor (action) representation. This link is realised at the cell assembly 'meso' level, and is evidenced by a cell asemblies reach spanning articulatory regions and either of the respective visual/motor areas.

The present study, for the first time, formed these three assemblies independently of each other(Figure 1). Then in simulation of a one shot learning episode only the auditory pattern and either the visual or motor pattern were presented causing both their respective asemblies to ignite and bind at the sites of heavy overlap.

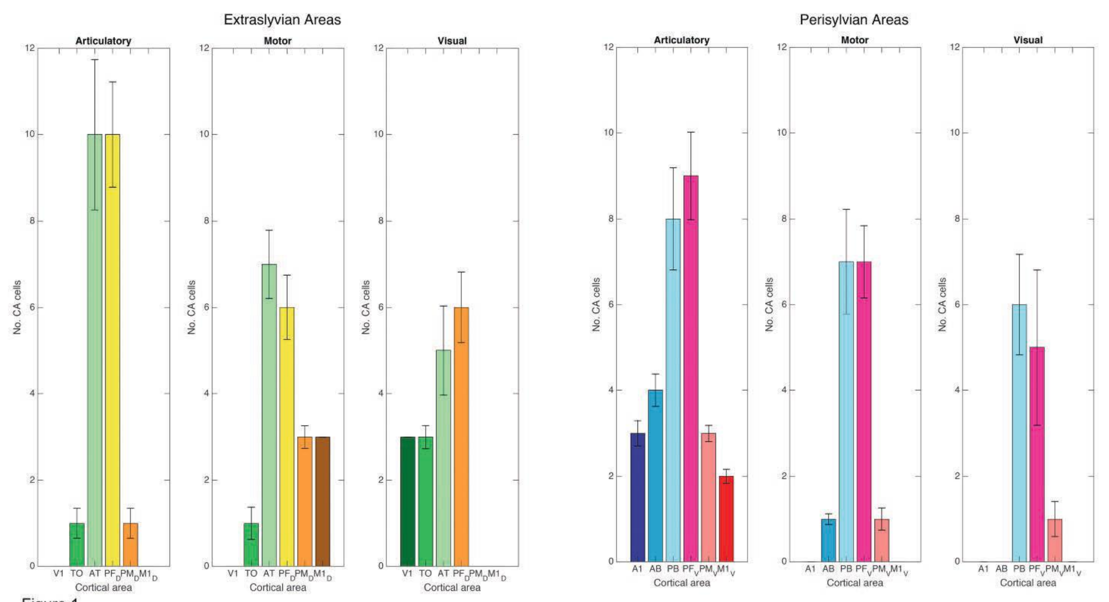


Figure 1
Number of cell assembly cells per area averaged within simulations across paradigms, and averaged over nine, 3000 presentations per pattern simulations.

Extraslyvian
- $M1_D$ Primary motor cortex
- PM_D Premotor
- PF_D Dorsolateral prefrontal
- AT Anterior-temporal
- TO Tempro-occipital
- V1 Early visual areas

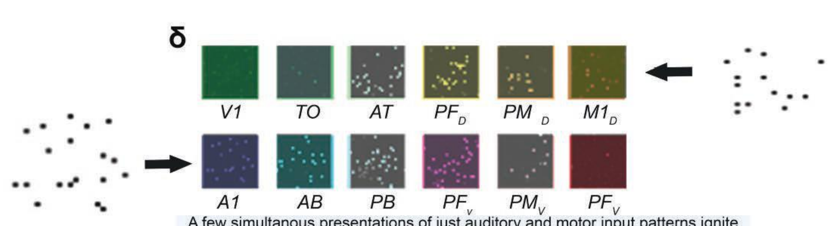
Perisylvian
- A1 Primary auditory cortex
- AB Auditory belt
- PB Auditory parabelt
- PF_V Inferior-prefrontal
- PM_V Premotor
- $M1_V$ Primary motor cortex

Intermittent results, *phase one*

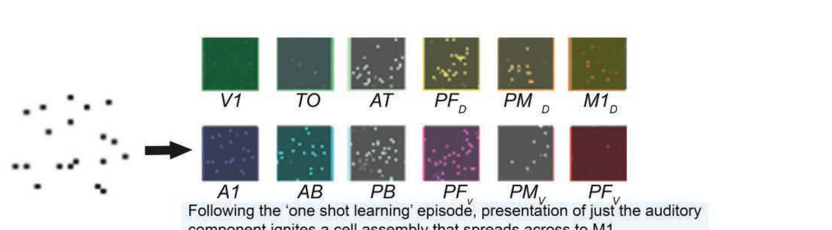
α. Six of twelve pattern pairs were presented concomitantly to Perisylvian phonological/articulatory input areas A1 and M1i. We can see a greater number of cell assembly cells recruited from these areas extending into the associativity hub areas PB, PF, AT and PF, and few in the peripheries of the Extraslyvian areas toward V1 and M1L.

β. Three of the twelve patterns were presented to Extraslyvian visual input area V1. We can see the cell assembly has spread, recruiting nodes through V1, TO and into the hub areas.

γ. Three of the twelve patterns were presented to Extraslyvian motor area M1L. We can see the cell assembly spread mirror that of the visual paradigm, with great numbers of cells extending from M1L through to hub areas. *During all training phases uncorrelated patterns were presented to non target areas & all areas recieve global noise.



A few simultanous presentations of just auditory and motor input patterns ignite their respective cell assemblies that already overlap in the hub region.
*Global inhibition parameter lowered relative to initial phase in the simulation of attention.



Following the 'one shot learning' episode, presentation of just the auditory component ignites a cell assembly that spreads across to $M1_D$.

Our experiments have reproduced some topographical and temporal aspects of neurophysiological tracing of novel word learning produced by Shytyrov, 2011[5].

Though preliminary, findings here support the hypothesis that, existing modality independent cell assemblies spread into integrative hub regions explain the speed of fast language maps.

It is also apparent that the link between word and object /action referent may be formed purely in cortex, sans hippocampus.

Intermittent results, *phase two*

Phase two utilised these existing cell assemblies to facilitate the fast map:

δ. We presented only the auditory component of the articulatory/phonological pattern pair, simulating hearing the word whilst simultaneously stimulating either visual or motor cell assemblies. Initial results indicate that in just a few presentations the distinct cell assemblies had bound. This binding of modality independent cell assemblies represents the mapping of the sound of a word, the motor articulation and either the visual or motor representation constituting semantic grounding in line with previous research[1]. The relatively few presentations in this phase provide evidence for fast mapping in the cortex.

References and acknowledgements

1. Garagnani, M., & Pulvermüller, F. (2016). Conceptual grounding of language in action and perception: A neurocomputational model of the emergence of category specificity and semantic hubs. *European Journal of Neuroscience*, 43(6), 721-737. doi:10.1111/ejn.13145
2. Photo : https://pixabay.com/
3. Photo: https://en.wikipedia.org/wiki/File:Donald_Hebb.gif *retrieved June 2019.*
4. Hebb, D. O. (1949). *The Organization of Behavior: A Neuropsychological Theory.* New York: Wiley and Sons.
5. Shtyrov, Y. (2011). Fast Mapping of Novel Word Forms Traced Neurophysiologically. *Frontiers in Psychology*, 2. doi:10.3389/fpsyg.2011.00340
6. Carey, S., Bartlett, E., 1978. Acquiring a single new word
7. Braitenberg, V., & Schüz, A. (1991). *Global Activity, Cell Assemblies and Synfire Chains. Anatomy of the Cortex Studies of Brain Function,* 199-211. doi:10.1007/978-3-662-02728-8_34
8. Pulvermüller, F. (1999). Words in the brain's language. *Behavioral And Brain Sciences*, 22(2), 253-279. doi: 10.1017/s0140525x9900182x