The neural circuit basis of feature-binding in working memory

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Summary. *Binding* (or *swap*) *errors occur* in working memory tasks when a wrong response is in fact accurate relative to a non-target stimulus [1]. These errors reflect the failure to maintain bundled in memory the conjunction of features that define one object, and the mechanisms implicated remain unknown. Here, we tested the mechanism of synchrony across feature-specific neural assemblies [2]. We built a biophysical neural network model for working memory items defined by one color and one location. The model is composed of two one-dimensional attractor networks for working memory (as in [3]), one representing colors and the other one locations. These two networks are then connected via weak cortico-cortical excitation. Gamma-oscillations were induced during bump attractor activity through the interplay of fast recurrent excitation and slower feedback inhibition [3]. Binding between color and location was accomplished through the synchronization of pairs of bumps across the two networks via weak cortico-cortical excitation. As a result, different memorized items were held at different phases of the network's intrinsic oscillation. In some simulations, *swap errors* arose: "color bumps" abruptly changed their phase relationship with "location bumps". The model makes specific testable predictions that we addressed experimentally. Firstly, a uniform drive pulsating at the natural frequency of the networks stabilizes the bumps and reduces the incidence of swap errors. This was validated in behavioral experiments with oscillating visual placeholders, with a specific swap-reducing effect at theta range. Secondly, swap errors in the model are associated with a lower phase consistency of oscillatory activity in the delay period. We validated this prediction in MEG experiments, finding alpha-band phase changes specific to swap trials in fronto-parietal sensors.
Significance. We propose a plausible mechanism for working memory binding based on neural synchronization in spiking neural networks, and we support it with behavioral and neurophysiological (MEG) experiments in humans.

This is a joint work wit Ainsley Temudo, Vahan Babushkin, Tim Buschman, Kartik K Sreenivasan, and Albert Compte.

References

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