Oscillatory Mechanisms Underlying Working Memory Capacity

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State of Art

Working memory (WM) is a neurocognitive mechanism responsible for the active maintenance of information for the purpose of its ongoing processing. The most important feature of WM is its heavily limited capacity. A person can maintain from two up to six items in WM, with a mean capacity of four items (Cowan, 2001).

Recently, formal models, which describe storage as some kind of a_pattern of fast oscillations, appeared to be the most promising theoretical approach to WM's functioning and its limits (e.g. Usher, Cohen, Haarmann, & Horn, 2001). Such models explain capacity limits as an_emergent property of WM: as brain uses temporal coding for separating representations in WM, it is not able to pack many oscillations into one time interval, because they start to overlap. However, existing oscillatory models do not explain the fact that people do differ in capacity. We present a novel formal model of WM and we demonstrate which its features are responsible for individual differences in WM capacity.

The Model

The model consists of a buffer, which contains a certain number of elements. A level of internal activation x_i is assigned to each element *i*. The external output *y* of the element *i* in time *t* has been defined using a sigmoid function of x_i, according to the following function (1):

$$y_i(t) = \frac{1}{1+\exp(-\gamma x_i(t) - \frac{1}{2})}. \quad (1)$$

Changes in levels of activation of elements are controlled by the following equation (2):

$$\begin{aligned} x_i(t) = \; & x_i(t-1) + \frac{\lambda}{1+y_i(t-1)} \\ & + \alpha \sum_k \exp\big(x_k(t-1) - x_i(t-1)\big) \\ & - \beta \sum_j \exp\big(x_j(t-1) - x_i(t-1)\big) + \varepsilon(n). \end{aligned} \quad (2)$$

Parameter λ controls how much element *i* is autoactivated by the recurrent connections feeding its output back into it. Index *k* denotes elements which output at the similar levels as element *i* does. So, parameter *a* determines how much the outputs of elements, which oscillate close to element *i*, increase its activation. This accounts for the fact that neurons which fire in synchrony strongly influence their potentials. Parameter κ defines the temporal resolution of bindings: the larger κ, the more differently activated elements will be considered as bound within the same representation.

Index *j* denotes elements which fall out of $[y_i-\kappa, y_i+\kappa]$ range. These elements encode representations separate from a representation encoded by the elements *i* and *k*. Parameter β controls the strength of inhibition exerted by elements *j*. How much element *j* inhibits element *i* depends on a difference in the elements' activity.

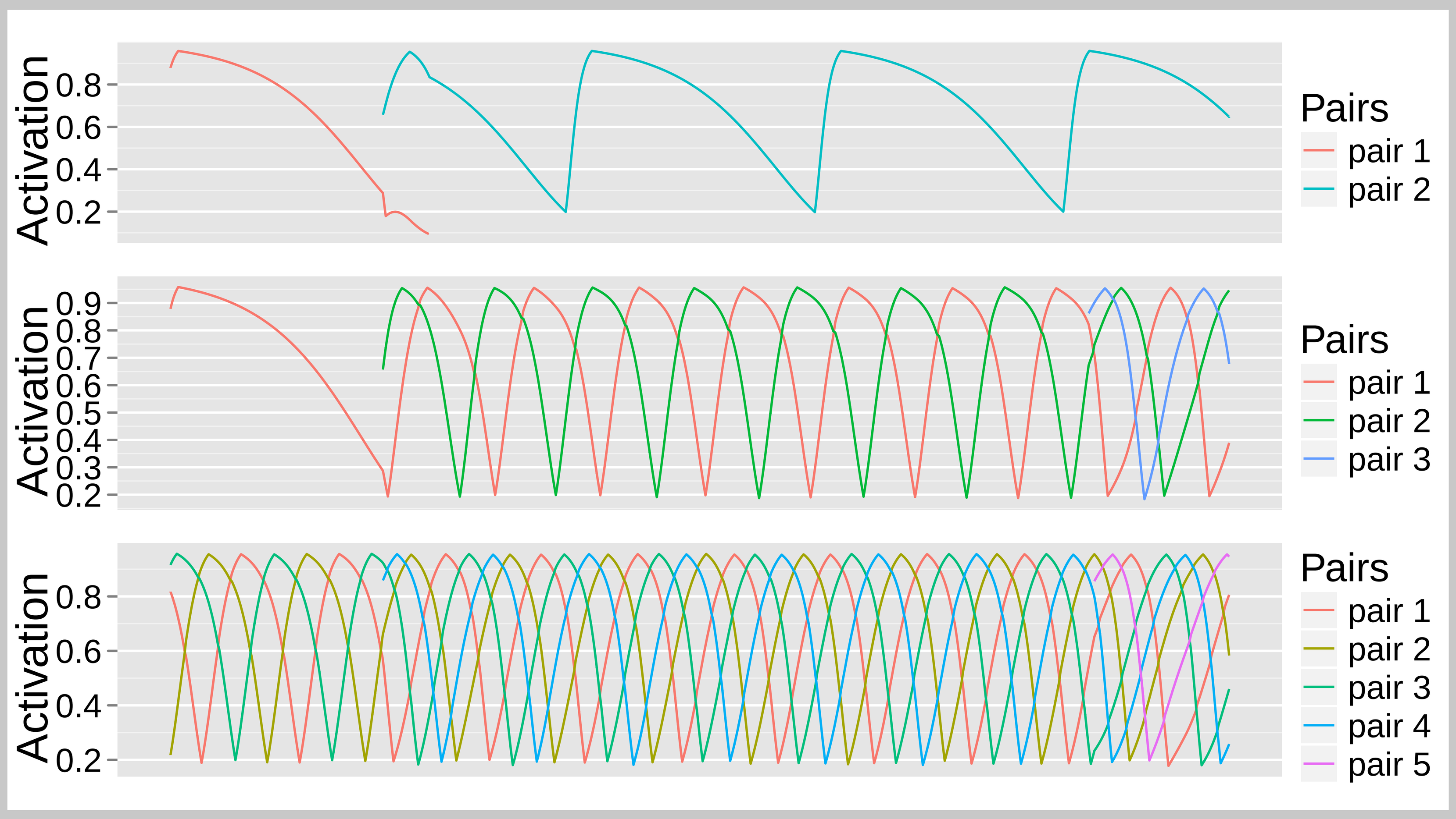

Figure 1. Patterns of oscillations for the lowest (one binding; upper panel), medium (three bindings; middle panel), and largest (five bindings; bottom panel) capacity. When k is insufficient, addition of a new pair eliminates an existing pair (see upper panel). When pairs' oscillations peaks are close they tend to achieve equal intervals (see middle panel).

Working of the Model

In the model, the capacity limit arises because addition of consecutive pairs increases the strength of inhibition that each pair receives. When this value surpasses the results of autoactivation and coactivation, the elements with the lowest activation levels start falling out of the buffer. Parameter β is the main determinant of the model's capacity. The higher β, the faster the elements start falling out of the buffer (see fig. 1).

The crucial of performed simulations (Andrelczyk et al. 2012) consisted of the replication of the distribution of PM capacity (*k*), which had been observed in the sample of 168 participants. In order to replicate the distribution of PM capacity the values of β were varied individually. Histograms of the observed and simulated distributions of *k* are presented in Fig. 2. Both distributions did not differ significantly (χ^2 = 6.97, *df* = 7, *p* = .431). R^2 value for observed and simulated data was .93.

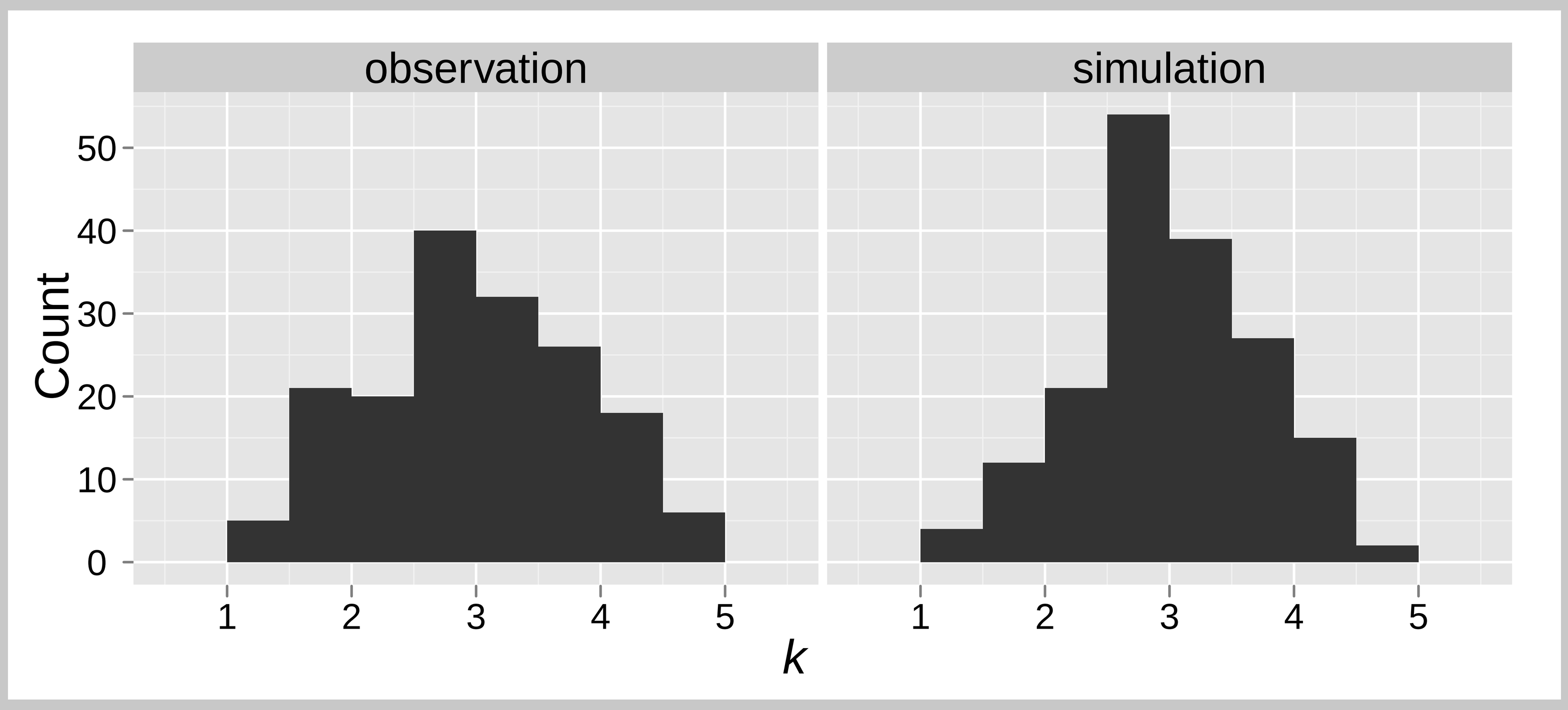

Figure 2. Histograms of k values derived from the two-array comparison task in case of human subjects (left panel) and simulated data (right panel).

References

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