Performance-optimization guided distribution of attentional resources

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In the visual system, attention improves information processing and is required to solve complex tasks such as shape detection and object recognition. On the neuronal level, it is found that different task demands, e.g. nature and specific combination of cues and cue validities, modulate response properties in many cortical areas in parallel [1]. Selective attention is assumed to be instrumental in orchestrating the flexible and efficient distribution of resources among brain areas to set up task-specific functional networks [2]. However, it is unclear how this process is organized on a functional level, and according to which principles computation is coordinated among different neuronal populations and visual areas.

Here, we investigate task-specific attentional distribution in a simplified framework where a stimulus is processed by two or more neuronal populations (or visual areas) which are specialized in representing different features such as orientation or color. We assume the task is to detect a stimulus change in one of its features, while a cue is given that matches the changing feature with a certain probability (cue validity). Adhering to physiological constraints, attention is modeled as a bounded gain change on the populations' outputs to a higher area decision population, whereas the whole input to the decision population is normalized [3] (**Fig. 1A**). Considering distributed attention as an optimization problem, we compute the gain factors minimizing error rates for the different populations engaged in the task by analytical gradient descent. We find that optimal gain factors depend on cue validity and change saliency, with attention also boosting the populations representing non-cued features if cue validity is below 100% and if change saliency is high. Furthermore, when attention spreads to non-cued features, we find that a multitude of attentional distributions exist that yield the same optimal performance (**Fig. 1B**).

Our results have important implications for empirical studies: first, we provide a first-principle explanation in a minimal framework of attentional modulation spreading also to non-cued feature dimensions or attributes. Second, the dependence of optimal modulation strength on task parameters and the degenerative nature of solutions in part of the parameter space implies that attention-related gain changes observed in animal studies might not be constant, but will change over time if e.g. cue validity is manipulated and if perceptual learning takes place.

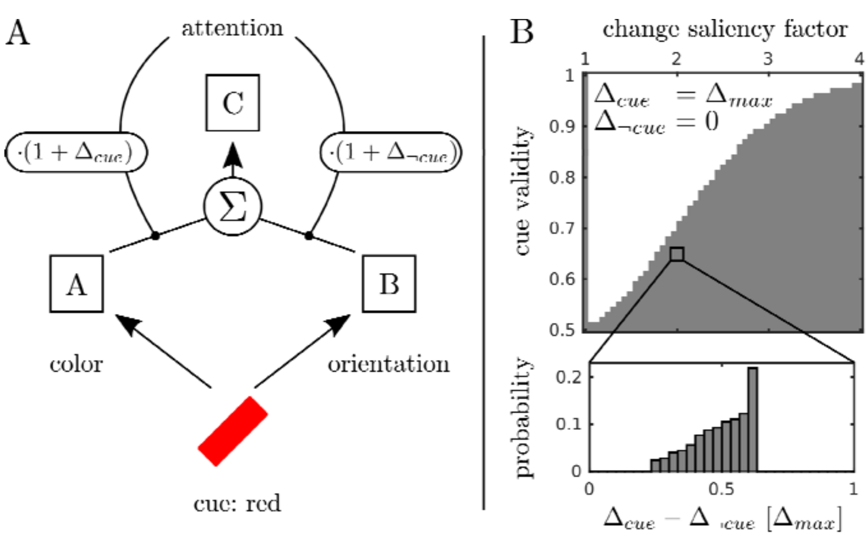

Figure 1. A: Schematic of the model setup with a two-feature stimulus. **B:** In the white region, optimal performance is achieved by directing maximal attention towards the cued feature and none to the non-cued one. In the gray region, it is optimal to also attend to the non-cued feature. Here, solutions are degenerate such that a multitude of attentional configurations leads to the same optimal performance. The probability distribution of modulation differences illustrates this for one exemplary parameter set.

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