Generative model estimation through Expectation-Maximization allows insight into perceptual accumulation mechanisms

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The mechanisms at play when the brain integrates sensory information over time to reduce uncertainty over percepts have been the focus of intensive study in the last two decades [1,2]. Despite this effort, it has remained virtually impossible to experimentally tease apart distinct models for perceptual accumulation. This is largely due to the fact that in these models stochastic processes (either sensory or internal noise) play a large role and thus models only loosely constrain experimental data. Here we introduce a novel method based on generative models that reduces that part of stochasticity to its minimum and hence allows digging much more precisely into accumulation mechanisms. The method is applied in a context where, unlike the generic random-dot-motion task, perceptual information provided by each sensory sample can be quantified [3,4]. Moreover, the method is novel in providing a common generative model for both response choices and reaction time; those two behavioral measures provide rich information to constrain the generative model, especially in the context of speeded tasks. The method is based on parameter estimation through an Expectation-Maximization algorithm in generative models that combine three cognitive components: an accumulation stage (how sensory samples are integrated), a decision stage (including thresholds and noise) and a post-decision stage (modeling the time distribution from decision to the motor response). We first tested the method on synthetically generated stimuli, showing model parameters could be accurately estimated (the EM algorithm apparently encountered the global maximum of the likelihood function). Then the method was applied to a speeded-reaction time task where subjects must judge the overall orientation of successive visual stimuli. Results very clearly arbitrate between different variants of the distinct model components both in terms of log-likelihood and fitting to experimental data characteristics. Notably we show that the decision threshold remains constant throughout stimulus presentation while decision noise increases sub-linearly, in line with diffusion-to-boundary hypothesis. Overall, the results open a promising path towards understanding of the refined mechanisms of perceptual accumulation. More generally, they illustrate the power of fitting generative models of behavior to human psychophysics data for unveiling cognitive mechanisms in action.

References

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