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Learning in volatile environments with the Bayes factor surprise. (English) Zbl 1469.91040

Summary: Surprise-based learning allows agents to rapidly adapt to nonstationary stochastic environments characterized by sudden changes. We show that exact Bayesian inference in a hierarchical model gives rise to a surprise-modulated trade-off between forgetting old observations and integrating them with the new ones. The modulation depends on a probability ratio, which we call the Bayes Factor Surprise, that tests the prior belief against the current belief. We demonstrate that in several existing approximate algorithms, the Bayes Factor Surprise modulates the rate of adaptation to new observations. We derive three novel surprise-based algorithms, one in the family of particle filters, one in the family of variational learning, and one in the family of message passing, that have constant scaling in observation sequence length and particularly simple update dynamics for any distribution in the exponential family. Empirical results show that these surprise-based algorithms estimate parameters better than alternative approximate approaches and reach levels of performance comparable to computationally more expensive algorithms. The Bayes Factor Surprise is related to but different from the Shannon Surprise. In two hypothetical experiments, we make testable predictions for physiological indicators that dissociate the Bayes Factor Surprise from the Shannon Surprise. The theoretical insight of casting various approaches as surprise-based learning, as well as the proposed online algorithms, may be applied to the analysis of animal and human behavior and to reinforcement learning in nonstationary environments.

MSC:
91E40 Memory and learning in psychology
62P15 Applications of statistics to psychology
62F15 Bayesian inference

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References:
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