Exact Combinations of Multivariate Confidence Curves with Applications to High Energy Physics

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In high-energy-physics analyses, Wilks' theorem applied to the profile-likelihood ratio are commonly used to derive p-values and confidence intervals of the parameters of interest. This method naturally handles nuisance parameters, and allows for straightforward combination of information from multiple sources. However, the required regularity conditions of Wilks' theorem can be violated in realistic analyses, for example with small samples or when parameters are constrained to boundaries. Thus, naively applying Wilks' theorem in these settings can lead to severe miscoverage. Several alterative methods have been proposed to address this issue, but they can be mathematically intricate or computationally intensive. We propose an alternative inference framework based on combinations of confidence distributions and their associated confidence curves. These are frequentist distributional representations of parameter uncertainty, analogous to Bayesian posteriors but without requiring priors. In our method, we construct source-specific confidence curves and combine them into a joint multivariate confidence curve using a construction that preserves coverage. Additionally, nuisance parameters can be profiled out without compromising frequentist validity. We illustrate the method with two high energy physics examples: Poisson signal-plus-background models and effective field theory cross-section fits with boundaries stemming from non-linear parameter dependencies. In the non-regular settings, the proposed approach achieves nominal coverage where Wilks-based inference fails. In regular, high-count regimes, the two methods coincide, confirming asymptotic equivalence.

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