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Efficient tuning of particle accelerator emittance via Bayesian algorithm execution and virtual objectives

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Although beam emittance is critical for the performance of high-brightness accelerators, optimization is often time limited as emittance calculations, commonly done via quadrupole scans, are typically slow. Such calculations are a type of *multi-point queries*, i.e. each query requires multiple secondary measurements. Traditional black-box optimizers such as Bayesian optimization are slow and inefficient when dealing with such objectives as they must acquire the full series of measurements, but return only the emittance, with each query. We propose using Bayesian Algorithm Execution (BAX) to instead query and model individual beam-size measurements. BAX avoids the slow multi-point query on the accelerator by acquiring points through a *virtual objective*, i.e. calculating the emittance objective from a fast learned model rather than directly from the accelerator. Here, we use BAX to minimize emittance at the Linac Coherent Light Source (LCLS) and the Facility for Advanced Accelerator Experimental Tests II (FACET-II). In simulation, BAX is 20x faster and more robust to noise compared to existing methods. In live LCLS and FACET-II tests, BAX performed the first automated emittance tuning, matching the hand-tuned emittance at FACET-II and achieving a 24% lower emittance at LCLS. Our method represents a conceptual shift for optimizing multi-point queries, and we anticipate that it can be readily adapted to other similar problems commonly found in particle accelerators and beyond.

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