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Reinforcement Learning Beyond Greedy Optimisation for Delayed-Consequence Accelerator Control

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Most accelerator control systems assume that the effect of an action can be evaluated locally and immediately. While greedy approaches work in near-linear regimes and Bayesian Optimisation (BO) is now standard for black-box tuning, both are essentially static optimisers and struggle in dynamic tasks with delayed consequences, where even adaptive BO remains time-myopic and lacks explicit temporal credit assignment for system memory and long-range machine evolution.

We investigate three relevant forms of delayed consequences: explicit action latency (field settling delays response), magnetic hysteresis (output depends on change history), and ballistic amplification (small upstream kicks grow through nonlinear optics and apertures, causing downstream loss).

Using a high-fidelity XSuite model of the AWAKE electron line, we benchmark a reinforcement learning controller against an inverse-response greedy optimiser and BO. The learning-based method anticipates delayed effects and avoids failure regions where both baselines fail, indicating that delayed-consequence regimes are a key class of accelerator control problems where horizon-aware model-based or learning-based methods clearly outperform current practice.

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