Neural optimal feedback control with local learning rules

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Optimal Feedback Control (OFC)

- Optimal Feedback Control (OFC) is a framework from control theory that describes how to compute actions (or controls) to achieve a goal in the most efficient way, especially in systems with uncertainty, like noise or delayed feedback.
    - OFC continuously adjusts actions based on real-time sensory feedback, using an internal model to predict future states and minimize a cost (like error or effort).

Kalman Filtering and Linear-Quadratic Regulator (LQR)

- Classical approaches like Kalman filtering and linear-quadratic regulators (LQR) work well in theory, but they're not biologically plausible.
- The **Kalman Filter (for Estimation)** is an algorithm used to **estimate** the hidden state of a system (like position or velocity) from noisy observations.
    - It combines predictions from a model with actual noisy observations to get the best estimate of the current state.
    - Example: You're tracking a moving object (like your hand). You don't see it clearly due to noisy visual input, but you can predict where it's going based on how it was moving. The Kalman filter fuses that prediction and the noisy observation to guess where your hand really is.
- The **Linear-Quadratic Regulator (LQR) (for Control)** is a method to compute the optimal action (**control**) to apply to a system to minimize a cost, assuming the system's dynamics and noise are known and linear.
    - Given a current estimate of the state, it outputs a control action that minimizes a long-term cost function (usually quadratic—e.g., penalties on error and effort).
    - Example: It helps you smoothly move your hand to a target while using the least amount of energy and keeping the motion accurate.
- Why these aren't biologically plausible:
    - They require exact knowledge of system dynamics and noise statistics.
    - They often involve matrix operations, like inversion and solving Riccati equations—hard to do with real neurons.
    - They assume instant access to clean data (**no delays**) and global updates across the system.
    - Learning in these frameworks isn't local (i.e., neurons can't just use their own input/output to update weights).

- So, while Kalman filters and LQRs are mathematically elegant, the brain probably doesn't implement them directly, which is why papers like this one try to build **neural approximations that use biologically plausible rules**.