BMC Neuroscience

Poster presentation

Open Access

Critical adaptive control may cause scaling laws in human behavior

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from Eighteenth Annual Computational Neuroscience Meeting: CNS*2009
Berlin, Germany. 18–23 July 2009

Published: 13 July 2009

BMC Neuroscience 2009, **10**(Suppl 1):P17 doi:10.1186/1471-2202-10-S1-P17

This abstract is available from: http://www.biomedcentral.com/1471-2202/10/S1/P17

When humans perform closed-loop control tasks like in upright standing or while balancing a stick, their behavior exhibits non-Gaussian fluctuations with long-tailed distributions [1,2]. The origin of these fluctuations is not known, but their statistics suggests a fine-tuning of the underlying system to a critical point [3]. We investigated whether self-tuning may be caused by the annihilation of local predictive information due to success of control [4]. We found that this mechanism can lead to critical noise amplification, a fundamental principle that produces complex dynamics even in very low-dimensional state estimation tasks. It generally emerges when an unstable dynamical system becomes stabilized by an adaptive controller that has a finite memory [5]. It is also compatible with control based on optimal recursive Bayesian estimation of a varying hidden parameter. Starting from this theory, we developed a realistic model of adaptive closed-loop control by including constraints on memory and delays. To test this model, we performed psychophysical experiments where humans balanced an unstable target on a computer screen. It turned out, that the model reproduces the long tails of the distributions together with other characteristics of the human control dynamics. Fine-tuning the model to match the experimental dynamics identifies parameters characterizing a subjects control system which can be independently tested. Our results suggest that the nervous system involved in closed-loop motor control nearly optimally estimates system parameters on-line from very short epochs of past observations.

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