

From Atmospheric Forecasting to Neurological Inspiration: The Emerging Role of Brain Emotional Learning in Environmental Modeling

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Abstract

The intersection of computational neuroscience and environmental modeling has birthed novel algorithms that emulate brain-inspired emotional learning. One such contribution is the BELBFM (Brain Emotional Learning Based on Basic and Functional Memories) model, recently proposed for dual-height wind speed forecasting. While designed for meteorological applications, the structure and function of BELBFM echo principles long studied in neurobiology. In this commentary, we explore the neurological underpinnings of BELBFM, its potential feedback to cognitive modeling, and the broader implications of emotionally inspired computation in both natural and artificial systems.

Introduction

Neuroscience has traditionally informed computational models of decision-making and adaptive learning. The amygdala–orbitofrontal circuit, central to emotional regulation and feedback processing, has particularly inspired architectures aimed at simulating behavior under uncertainty. Our recent work in *Scientific Reports* introduced a biologically plausible model—BELBFM—for predicting wind speeds at 10 and 100 meters [1]. While originally applied to environmental systems, its architecture opens new vistas for understanding adaptive mechanisms akin to those observed in the human brain.

Neurobiological Foundations of BELBFM

BELBFM leverages five key functional components: Sensory Input, Thalamus, Sensory Cortex, Amygdala, and Orbitofrontal Cortex. This mirrors the limbic system's architecture, particularly the fast and slow sensory pathways feeding into the amygdala and orbitofrontal cortex—a principle well-documented by LeDoux and others. BELBFM encodes a dual-memory mechanism:

- Basic memory mirrors short-term, stimulus-response patterns akin to conditioned fear responses.
- Functional memory resembles experience-based regulation seen in orbitofrontal valuation, enabling context-dependent modulation.

Notably, the model employs performance-driven feedback analogous to neuromodulation, adjusting its behavior based on historical prediction error—an idea resonant with reward prediction error signals in dopaminergic systems.

Cognitive Models and Feedback Learning

The success of BELBFM in handling non-linear, noisy atmospheric data lends credibility to emotionally inspired learning for broader cognitive models. Unlike traditional backpropagation-based networks, BELBFM emphasizes distributed memory structures, modular processing, and fusion through adaptive weighting—features that parallel emerging views of brain connectivity and functional specialization. This approach may offer a computational scaffold for simulating flexible, feedback-sensitive behavior in uncertain environments—a hallmark of human cognition [2].

Implications for Neurology and Computational Psychiatry

Clinical relevance and translational potential

Beyond theoretical implications, BELBFM can serve as a computational probe for clinical neuroscience. By tuning the relative weights of basic and functional memories, the model can mimic patterns of dysregulation observed in psychiatric and neurological conditions. For example, excessive dominance of basic memory may reflect the hyper-reactivity of the amygdala in anxiety disorders, whereas impaired functional memory control resembles orbitofrontal deficits seen in obsessive-compulsive disorder or addiction. Such adaptability provides a platform for exploring mechanistic hypotheses, testing therapeutic strategies *in silico*, and even informing the design of neuroadaptive technologies, including diagnostic classifiers and brain–computer interfaces [3]. Thus, BELBFM is not only a tool for atmospheric modeling but also a bridge toward translational applications in clinical neuroscience.

BELBFM's architecture, though applied to wind modeling, is reminiscent of dysregulation models in psychiatric disorders. For instance:

- Amygdala hyperactivity (e.g., in anxiety) can be simulated by adjusting basic memory dominance.
- Orbitofrontal dysfunction (e.g., in OCD or addiction) can be explored by altering the influence of functional memory.

Such simulations could be adapted to explore hypotheses about neurological diseases, emotional learning deficits, or cognitive-behavioral adaptation.

Moreover, BELBFM's pruning-based efficiency and robust generalization across datasets suggest potential for real-time neuroadaptive systems, such as brain–computer interfaces or emotional prostheses.

Conclusion and Future Directions

The BELBFM model exemplifies how biologically-inspired architectures can transcend disciplinary boundaries. What began as a tool for wind forecasting now offers fertile ground for cognitive modeling and neuro-computational exploration. Future extensions may include incorporating dynamic plasticity rules, multi-agent interactions, or neurochemical modulation, pushing the model closer to biologically grounded emotional computation.

References

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