Towards Self-Organizing Autonomous Brain-Inspired Cognitive Architectures

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Abstract

This talk will review recent progress towards modeling how a person, animal, or machine can autonomously learn to adapt in real time to a complex and changing world. The word 'autonomous' refers to the ability of such a system to learn on its own from its environment, whereas 'real time' refers to the ability of the system to learn moment-by-moment, or incrementally, from its environment. This work emphasizes the system level, because a full understanding of learning requires that it be understood within a system that controls adaptive behaviors. Multi-dimensional learned information fusion plays a central role to enable the brain to combine multiple information sources to adaptively solve complex behavioral problems, and to solve outstanding technological problems that depend on intelligent and adaptive decision making and prediction in response to high-dimensional, uncertain, and ever-changing data.

No single type of learning and memory accomplishes a broad spectrum of behavioral tasks. The ability of each process to successfully compute some properties prevents it from computing other, complementary, properties. My colleagues and I have, over the years, shown that many brain processes are organized, not into independent modules, but rather into parallel processing streams that compute complementary properties. Hierarchical and parallel interactions within and between these streams overcome complementary weaknesses of each stream to realize behavioral competences that are needed for survival. Our research teams are organized to explain how complementary learning and memory mechanisms interact within these functional systems to realize these behavioral competences.

More specifically, a long-range scientific research goal is to develop biological, general-purpose, real-time, autonomous adaptive systems for both visual intelligence and auditory intelligence. Visual intelligence includes such interacting processes as visual perception, object recognition, visually-based cognition, visually-based emotion, visually-based planning, spatial navigation, and eye movement tracking. Auditory intelligence includes such interacting processes as auditory streaming, auditory perception, speech recognition, speech production, language understanding, language-based cognition, and language-based emotion. A coordinated attack on several of these problems has been developed which can facilitate the solution of each of them.

The current talk will illustrate recent progress with one or more examples. One such example describes a neural model that proposes answers to the following basic questions that are of equal interest to understanding the biological brain as they are to designing brain-inspired cognitive architectures for technology: What is an object? How does the brain learn what an object is without any external supervision? In particular, how does the brain learn to recognize a complex object from multiple viewpoints? How does the brain know how to intelligently scan a scene with eye movements? How is this accomplished even before the brain knows anything about a scene or the objects in it? The proposed solution clarifies how visual boundaries and surfaces, spatial and object attention, visual search using eye movements, and object category learning are coordinated to learn view-invariant object categories. It involves the coordinated dynamics of multiple brain regions, including cortical areas V1, V2, V3, V4, ITp, ITa, PPC, LIP, and PFC. Such examples provide insights into qualitatively new designs for coordinated parallel and hierarchitcal processing in multiple specialized processors that each suffer from local ambiguities and complementary deficiencies.

A related example clarifies why the cerebral cortex is organizing into laminar circuits, and how variants of a shared circuit design can support all types of higher-order biological intelligence. This fact raises the basic question: How does laminar computing give rise to biological intelligence? The talk will illustrate how the brain may coordinate multiple levels of thalamocortical and corticocortical processing to rapidly learn, and stably remember, important information about a changing world. The model clarifies how bottom-up and top-down processes work together to realize this goal, notably how

processes of learning, expectation, attention, resonance, and synchrony are coordinated. The model hereby clarifies, for the first time, how the following levels of brain organization coexist to realize cognitive processing properties that regulate fast learning and stable memory of brain representations: single cell properties, such as spiking dynamics, spike-timing-dependent plasticity (STDP), and acetylcholine modulation; detailed laminar thalamic and cortical circuit designs and their interactions; aggregate cell recordings, such as current-source densities and local field potentials; and single cell and large-scale inter-areal oscillations in the gamma and beta frequency domains. In particular, the model predicts how laminar circuits of multiple cortical areas interact with primary and higher-order specific thalamic nuclei and nonspecific thalamic nuclei to carry out attentive visual learning and information processing. Variants of such laminar circuit models have been used to provide unified explanations and predictions of behavioral and neurobiological data about vision and cognitive information processing.

Such examples of Complementary Computing and Laminar Computing show that understanding the brain, as well as brain-inspired cognitive architectures, requires the introduction of new computing paradigms that represent a radical break with traditional approaches to artificial intelligence.

References

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