The Brain's Cognitive Dynamics: The Link Between Learning, Attention, Recognition, and Consciousness

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Abstract. The processes whereby our brains continue to learn about a changing world in a stable fashion throughout life are proposed to lead to conscious experiences. These processes include the learning of top-down expectations, the matching of these expectations against bottom-up data, the focusing of attention upon the expected clusters of information, and the development of resonant states between bottom-up and top-down processes as they reach a predictive and attentive consensus between what is expected and what is there in the outside world. It is suggested that all conscious states in the brain are resonant states, and that these resonant states trigger learning of sensory and cognitive representations when they amplify and synchronize distributed neural signals that are bound by the resonance. Thus, processes of learning, intention, attention, synchronization, and consciousness are intimately bound up together.

The name Adaptive Resonance Theory, or ART, summarizes the predicted link between these processes. Illustrative psychophysical and neurobiological data have been explained and quantitatively simulated using these concepts in the areas of early vision, visual object recognition, auditory streaming, and speech perception, among others. It is noted how these mechanisms seem to be realized by known laminar circuits of the visual cortex. In particular, they seem to be operative at all levels of the visual system. Indeed, the mammalian neocortex, which is the seat of higher biological intelligence in all modalities, exhibits a remarkably uniform laminar architecture, with six characteristic layers and sublamina. These known laminar ART, or LAMINART, models illustrate the emerging paradigm of Laminar Computing which is attempting to answer the fundamental question: How does laminar computing give rise to biological intelligence? These laminar circuits also illustrate the fact that, in a rapidly growing number of examples, an individual model can quantitatively simulate the recorded dynamics of identified neurons in anatomically characterized circuits *and* the behaviors that they control. In this precise sense, the classical Mind/Body problem is starting to get solved.

It is further noted that many parallel processing streams of the brain often compute properties that are complementary to each other, much as a lock fits a key or the pieces of a puzzle fit together. Hierarchical and parallel interactions within and between these processing streams can overcome their complementary deficiencies by generating emergent properties that compute complete information about a prescribed form of intelligent behavior. This emerging paradigm of Complementary Computing is proposed to be a better paradigm for understanding biological intelligence than various previous proposals, such as the postulate of independent modules that are

specialized to carry out prescribed intelligent tasks. Complementary computing is illustrated by the fact that sensory and cognitive processing in the What processing stream of the brain, that passes through cortical areas V1-V2-V4-IT on the way to prefrontal cortex, obey top-down matching and learning laws that are often complementary to those used for spatial and motor processing in the brain's Where/How processing stream, that passes through cortical areas V1-MT-MST-PPC on the way to prefrontal cortex. These complementary properties enable sensory and cognitive representations to maintain their stability as we learn more about the world, while allowing spatial and motor representations to forget learned maps and gains that are no longer appropriate as our bodies develop and grow from infanthood to adulthood. Procedural memories are proposed to be unconscious because the inhibitory matching process that supports their spatial and motor processes cannot lead to resonance.

Because ART principles and mechanisms clarify how incremental learning can occur autonomously without a loss of stability under both unsupervised and supervised conditions in response to a rapidly changing world, algorithms based on ART have been used in a wide range of applications in science and technology.

Biography

Stephen Grossberg is Wang Professor of Cognitive and Neural Systems and Professor of Mathematics, Psychology, and Biomedical Engineering at Boston University. He is the founder and Director of the Center for Adaptive Systems, founder and Chairman the Department of Cognitive and Neural Systems, founder and first President of the International Neural Network Society (INNS), and founder and co-editor-in-chief of the official journal, Neural Networks, of INNS and the European Neural Network Society (ENNS) and Japanese Neural Network Society (JNNS). Grossberg has served as an editor of many other journals, including Journal of Cognitive Neuroscience, Behavioral and Brain Sciences, Cognitive Brain Research, Cognitive Science, Adaptive Behavior, Neural Computation, Journal of Mathematical Psychology, Nonlinear Analysis, IEEE Expert, and IEEE Transactions on Neural Networks. He was general chairman of the IEEE First International Conference on Neural Networks and played a key role in organizing the first annual INNS conference. Both conferences have since fused into the International Joint Conference on Neural Networks (IJCNN), the largest conference on biological and technological neural network research in the world. His lecture series at MIT Lincoln Laboratory on neural network technology was instrumental in motivating the laboratory to initiate the national DARPA Study on Neural Networks. He has received a number of awards, including the 1991 IEEE Neural Network Pioneer award, the 1992 INNS Leadership Award, the1992 Thinking Technology Award of the Boston Computer Society, the 2000 Information Science Award of the Association for Intelligent Machinery, the 2002 Charles River Laboratories prize of the Society for Behavioral Toxicology, and the 2003 INNS Helmholtz award. He was elected a fellow of the American Psychological Association in 1994, a fellow of the Society of Experimental Psychologists in 1996, and a fellow of the American Psychological Society in 2002.

He and his colleagues have pioneered and developed a number of the fundamental principles, mechanisms, and architectures that form the foundation for contemporary neural network research, particularly those which enable individuals to adapt autonomously in real-time to unexpected environmental changes. Such models have been used both to analyse and predict interdisciplinary data about mind and brain, and to suggest novel architectures for technological applications.

Grossberg received his graduate training at Stanford University and Rockefeller University, and was a Professor at MIT before assuming his present position at Boston University.

Core modeling references from the work of Grossberg and his colleagues for neural models of working memory and short-term memory, learning and long-term memory, expectation, attention, resonance, synchronization, recognition, categorization, memory search, hypothesis testing, and consciousness in vision, visual object recognition, audition, speech, cognition, and cognitive-emotional interactions. Some articles since 1997 can be downloaded from http://www.cns.bu.edu/Profiles/Grossberg

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