

Stochastic Computational Associative Memories: Neuromorphic Architectures Beyond Moore's Law

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In the next ten years we will witness a juncture point in the field of microelectronics. Within this period traditional scaling of transistors in CMOS technology, will have reached its physical limits. However, advances in nanoscale structures such as carbon nanotubes and semiconducting wires have the potential to add new functionality by augmenting traditional processing in nano-CMOS technologies. We will move slowly but steadily towards an era where breakthroughs in the field, will not be driven only by research aimed at exploiting and managing the exponential rate of digital transistor density in CMOS technology (Moore's Law). Research and development in the field will strive towards benefits from methodologies that allow advances in the structural complexity of micro-systems. These will lead to new paradigms for computing and information processing whose foundation is the emerging new and novel technologies that complement current CMOS devices, circuits and architectures. In the near and mid term time horizon, we view CMOS technology as the foundation for the interfaces and computational elements that will form the bridge between the nanoscale structures and the macro-scale world in the computational sensor architectures for autonomous cognitive behavioural systems. From an architectural viewpoint, we take inspiration from Nature. Biological information processing systems employ dynamic matter and learning at all levels in an amazing network of complex structures of different scales, from the nano to the micro and macro. Both biological brains and sensory organs operate at performance levels set by fundamental physical limits, under severe constraints of size, weight and energy resources and they are indeed engineering marvels of heterogeneous integration and structural complexity across different physical scales, from molecules, to cells to mesoscopic structures and all the way to macroscopic systems of human dimensions.

In an era where FLOPS are FREE, we FREE the FLOPS from inter-processor/memory communication constraints through a bio-inspired processing architecture. We call this architecture a Stochastic Computational Associative Memory (SCAM), because it operates in a regime where inherent device stochasticity is exploited for information processing. This paradigm for computing will depend on technological advances, for example the 3D integration of nano-CMOS technologies with new materials and processes such as PCM or organic semiconductors that will allow such scalable and dense information processing. Large scale associative processing leads naturally to elegant solutions to cognitive and perceptual problems in human language processing and vision. However, this framework is also powerful enough to allow for general purpose associative processing capable of solving numerical problems in HPC such as integration of non-linear differential equations, whose solutions can be formulated in a general inferential framework.