Biologically Inspired Computing in CMOL CrossNets

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Abstract

This extended abstract outlines my invited keynote presentation of the recent work on neuromorphic networks ("CrossNets") based on hybrid CMOS/nanoelectronic ("CMOL") circuits, in the space-saving Q/A format.

What is CMOL?

CMOL is a hybrid circuit consisting of a silicon (CMOS) chip augmented with a nanowire crossbar which features similar, two-terminal nanodevices at each crosspoint. The devices have resistive bistability, i.e. the latching switch functionality. Currently, digital CMOL circuits look like the most promising way to extend the Moore's Law for 10 to 15 years beyond the so-called "redbrick wall". Because of that promise, CMOL circuits are a subject of intensive development by several academic and industrial groups. (For a recent detailed review, see, e.g., [Lik08].)

What is CrossNet?

CMOL circuits are naturally suitable for mixed-signal neuromorphic networks ("CrossNets") – see, e.g., [Tür04, Lee06]. In such networks, neural cell somas are implemented in the CMOS subsystem, crossbar nanowires play the roles of axons and dendrites, and crosspoint latching switches serve as elementary synapses. The most fascinating feature of the CrossNet topology is that it enables the implementation of virtually arbitrary cell connectivity in (quasi-) 2D integrated circuits.

Why Bother?

The main motivation for CMOL CrossNet development is the very high potential areal density of CMOL CrossNets (beyond that of the mammal cerebral cortex, at similar connectivity $\sim 10^4$), and the very high operation speed of these networks – e.g., intercell latency below 1 microsecond at readily manageable power dissipation below 1 W/cm^2. I believe that CMOL CrossNets is the first hardware which may eventually be used for challenging the mammal (human?) cerebral cortex.

Q: Any Problems?

Sure – a lot, but some of them have been already overcome. In particular, we have shown that the binary character of the elementary synapses and a relatively high defect density (possible at the initial stage of CMOL technology development) do not prevent CrossNets from performing essentially all the tasks demonstrated earlier with software-implemented artificial neural networks, including associative memories [Tür04], pattern classifiers with supervised learning [Lee07], and dynamic controllers trained by global reinforcement in conditions of either instant or delayed reward [Ma07].

Besides several hardware challenges to CMOL technology [Lik08] (which may be soon met by electronic industry lured by its promise for digital circuits), I believe that the largest problem of CrossNets is finding for them suitable intermediate cognitive tasks - substantially more advanced than pattern recognition but still more humble than such long-term goals as reasoning and self-awareness.

CrossNet research at Stony Brook has been supported by AFOSR, DoD, MARCO (via FENA Center), and NSF.

References

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