Implementing biologically inspired architectures using microelectronics

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1 Aims

The eventual aim of this programme is the development of implementations of biologically inspired systems that can be deployed directly to enable levels of capability in processing data (particularly sensory data) normally associated with biological systems. Biological systems routinely process visual, auditory and olfactory data very rapidly, even when the data itself is of relatively poor quality. Purely software solutions based on logical abstractions have been the basis of many attempts made in artificial intelligence at solving these, but these attempts have succeeded only in pointing out the difficulties in the problems. Theoretical and simulation based research on neural systems ("Computational Neuroscience") has advanced a great deal in then last few years (see e.g. the work of Sejnowski, Senn, Koch, Maass, and many others), and the time is ripe for implementing some of these techniques electronically.

The difficulties in this programme arise because the neurophysiologists provide information about purely neurophysiological effects: they are generally not concerned with how these effects are turned into (useful) information processing. Computational neuroscientists build models of these systems, and often try to show how they might produce useful information processing. However, they too are a long way from the engineer who is trying to produce something which actually does do useful work using biologically based or inspired architectures. It is the bridging of this chasm that the present document discusses.

2 Bridging the Chasm

The distance from the biological system to the engineering system is large. Firstly, there is the question of understanding the biological system in an appropriate way, that is, in a way that allows one to re-build a functional version of the biological system. Clearly, one needs to understand both the why and the what of the processing: simply slavishly re-implementing in a different technology will not work. The most usual technique is to start from some what appear to be appropriate characteristics of the biological system design a (software or mathematical) model one can experiment with to gain a proper understanding of the system, and only eventually build a hardware system.

Secondly, there is the eventual implementation. Neurobiology uses many different charge carriers (ions), many forms of active elements (ion channels), and many forms of modulation of these ion channels (neuromodulators). Electronics has a less rich repertory. The circuitry may be analogue or digital: it may use standard FET techniques, or some more recent oinnovation: it may use current, voltage, or pulse based events to transfer information between elements. However, two things are clear:

the systems will be highly parallel This will be the case both at the on-chip circuit level and across chips. Such parallelism makes difficult demands on the electronic engineer: unlike processor or memory chips, the elements do not necessarily lend themselves to bus-based interconnection.

the systems is likely to be adaptive Adaptivity is necessary for a number of reasons: firstly, there will be differences in the sensors and circuitry across devices, and these differences will need to be compensated for. Secondly, and more importantly, the precise environments of the systems will be different for each system, and may well alter over time. A non-adaptive system would need to be "programmed" to cope with all possible scenarios, whereas an adaptive system may be able to learn elements of correct operation.

3 Notes

- Like for the Computing Grand Challenge, one needs to decide whether one is describing a "Man on the moon" type scenario, where the public can easily see what the work is about, and where there is a definite endpoint. Yet such a project really provides an aim for which numerous technologies are honed, rather than being a "common theme for long-term research"
- Obviously the area of this project is multidisciplinary, covering Neurophysiology as well as EE, and perhaps robotics as well. This doesn't make it easier to get funding.
- Another direction that one can take this work is towards then integration of neural and electronic systems: either towards assistive systems, or even towards the biocomputer in which some elements are implemented electronically and some neurally. There are certainly groups internationally interested in both of these areas. The former is driven partly by the need for technology to help the disabled (but there is interest as well in direct man/machine interfacing for industrial/military/other applications as well). The concept of a biocomputer is not new, but I personally have yet to be convinced that it is (i) possible and (ii) useful: indeed, I suggest that we are better to attempt to understand the mechanisms at work, then implement them in a technology which we do understand.
- A more concrete approach would be to suggest "Build a vision system that can understand natural scenes well enough for navigation through them" , or "Build an auditory system that can understand speech in realistic noise levels". These are both activities that biological systems can do: indeed, the former is achieved by relatively simple animals, although the latter is essentially human.