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'Silicon synapses self-correct for both mismatch and design inhomogeneities', S. A. Bamford, A. F. Murray and D. J. Willshaw

Biologically inspired electronics have been found to have built-in error correcting capabilities

a learning process*

Work on a neuromorphic chip carried out at the University of Edinburgh in the UK has revealed that the biological learning mechanism 'spike-timing-dependent plasticity' (STDP) reduces the variation in performance between neurons arising from both mismatch in fabrication and inhomogeneities in the electronic design.

"Biological neural networks have homeostasis built in at various levels, of which STDP is one form," said Dr Simeon Bamford who carried out the work. "As we continue to build neural hardware we can expect to benefit from these effects more and therefore worry less about process variations than we might otherwise have thought."

Control Issues

Neuromorphic engineering is used to model the electrical behaviour of biological neural networks, and a number of groups have made chips that model spiking neurons. These usually have an array of neuron circuits, each with a dedicated array of synapse circuits. The 'spikes', or electrical pulses which neurons use to communicate, are transmitted asynchronously as digital events from a sending neuron, usually through off-chip transmission circuitry, to one or more receiving synapses. Each synapse then contributes a current waveform to its neuron which integrates this charge and emits a spike of its own if a threshold is crossed.

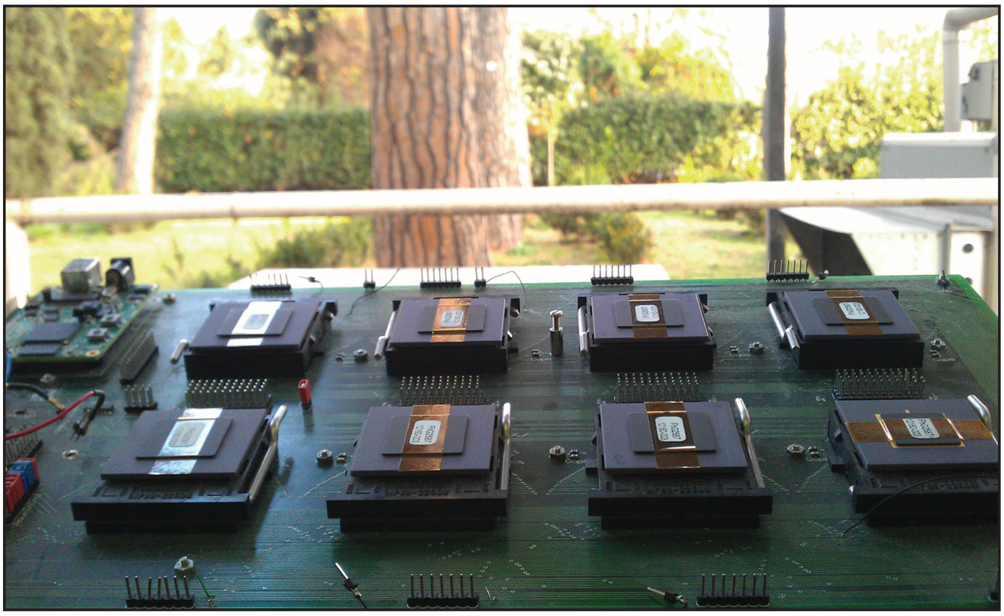
One issue that neuromorphic engineers face is 'mismatch', which causes different levels of excitability in which some neurons spike more easily or frequently than others. This mismatch can come from many possible sources, such as fabrication variations causing the capacitance of each neuron on which incoming synaptic currents are integrated to be slightly different.

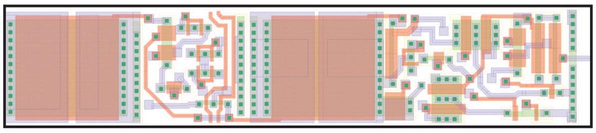
There are many techniques to control mismatch, such as making devices larger, or including programmable digital switches for calibrating the size of devices, but these have the disadvantage of making the design less compact.

A weight off the mind

Although Bamford was not specifically looking for a mismatch control solution, he discovered the built-in error correcting capability of biologically-inspired circuits during his PhD research at the University of Edinburgh.

"We were looking into how topographic maps form," he said. "This is the phenomenon where a 2D layer of neurons, such as those of the retina, send connections to a distant area, such as to the visual cortex, in a way that reconstructs the broad 2D layout of the first area (at the back of the brain there is something like a cinema projection of what the eyes see!) and yet applies some local transformation of the data (e.g. edge detection). This is an inherently interesting problem, and it may be necessary to build chips/neural systems which develop their (virtual) network wiring by themselves, in order to create computational hardware of the complexity of the brain."





TOP: An 8-chip test set-up was used to create a grid of neurons. Each chip contains 32 integrated neuron circuits and each neuron had 64 dedicated circuits for incoming synapses.
ABOVE: The layout of the analogue circuitry for the synapse, including the STDP circuitry (upper metal layers removed for clarity).
BOTTOM RIGHT: Dr Simeon Bamford

During this work, Bamford studied the effect of spike-timing-dependent plasticity (STDP). This is a learning mechanism that occurs at biological synapses in which the relative timing of spikes from neurons before and after a synapse causes changes in the synaptic strength.

It is already known that STDP can be used as an engineering solution against mismatch effects, but Bamford's work showed that, without specific engineering, STDP naturally causes a greater reduction in synaptic weights which impinge on the more excitable neurons.

"This might be expected from a previous computational investigation of STDP," said Bamford, "but in that case the difference in excitability came from different input frequencies. In our case the extra excitability came from process variations and differences between neurons introduced by the design. For example, we could have balanced the clock distribution network used for spike delivery at the expense of a more complex and possibly less compact design, but since we did not, we observed STDP acting to ameliorate the resulting differences between neurons."

Thinking of the future

This natural STDP mechanism could help to ease the design constraints of any application of spiking neural networks.

"The neuromorphic engineering field is going in two directions," said Bamford. "One is scaling up towards human-brain-scale emulation; another is towards applications in neural prosthesis. I also think we have a lot to gain by working with higher-level primitives than neurons and synapses, i.e. modelling and creating hardware models of the aggregate behaviour of whole populations of neurons, in order to better understand observable brain dynamics."