Polychronization: Computation With Spikes

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In the mammalian neocortex, pyramidal neurons often project to distant regions resulting in axonal conduction delays of tens of milliseconds. Synchronous spiking of such neurons may not be effective to fire a given postsynaptic cell, since the spikes might arrive to the postsynaptic cell at drastically different times. To excite the cell, the presynaptic neurons must fire with certain spike-timing patterns determined by the delays. Simulating a network of neocortical spiking neurons with conduction delays and spike-timing dependent plasticity (STDP), we found that spiking neurons spontaneously self-organized into stable groups and fire such repetitive spike-timing patterns with a millisecond precision.

Because the spikes in the pattern are not synchronous, but time-locked to each other, we refer to such activity as *poly*chronous, where *poly* means *many* and *chronous* means *time* or *clock* in Greek. Polychrony should be distinguished from asynchrony, since the latter does not imply reproducible time-locked patterns, but usually describes noisy random non-synchronous events. In contrast, polychrony implies a highly structured stereotypical spiking activity where each neuron fires at a precisely determined time.

We refer to each group of neurons capable of generating such an activity as a polychronous group. The theoretical existence of such groups was anticipated by Bienenstock (1995) and Gerstner et al. (1996). However, no one has expected that the number of coexisting polychronous groups could be greater than the number of neurons in the network, sometimes even greater than the number of synapses. That is, each neuron was part of many groups, firing with one group at one time and with another group at another time, resulting in an unprecedented memory capacity of the system. Retrospectively thinking, it is not surprising, since the networks we consider have delays, and hence are infinite-dimensional from the pure mathematical point of view.

If type permits, we will speculate on the significance of such polychronous activity in cognitive neural computations.

References

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