Why is neural spike transfer stochastic? String verification in the brain

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Noise-based logic, brains and computers

Noise-based logic (NBL) [1], which has been inspired by the fact that the neural signals in the brain are stochastic, utilizes independent stochastic processes as well as their superposition to carry the logic signal. The *brain logic* version [2] of NBL has been motivated by the following observations:

(*i*) The number of neurons in the brain is similar to the number of switching elements (MOS transistors) in a modern flash drive and about 10% of those of a Macbook Air laptop.

(*ii*) Moreover, the maximum frequency of neural spikes is about 20 million times less than the clock frequency.

(*iii*) On top of that, neural spike sequences are stochastic, which suggests that their information channel capacity is further limited.

The above facts indicate that the classical suggestions, that *neural information is statistical* and is carried by the *mean frequency of spikes* or *their cross-correlation* (between spike trains), are likely untrue and:

(*a*) single neural spikes potentially carry orders of magnitude more information than a single bit, and

(*b*) the brain uses a number of special-purpose operations that allow it to achieve *reasonably accurate but not perfect* results in a short time (with relatively small "brain-hardware" and time complexity).

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Figure 1: Simple demonstration of the difference between the ways of operation of a brain and a computer.

The fact that the brain operates in a different way than a computer can be easily demonstrated. For example, see Figure 1, where the lines contain strings that are identical with the exception of one line where there is a small difference. The brain detects the different line immediately without reading each character in each line. A computer, however, would scan the image character-by-character and then do a comparison accordingly.

If we try to do it in the computer's way, reading and comparing each element in the tasks described above, we would perform extremely slowly in a large system.

String verification by brain logic

In this talk we show a method on how neurons can solve a string verification problem very rapidly, with a non-zero error probability that decreases exponentially versus the time of operation. The non-brain version of this computational scheme, based on bipolar random telegraph waves, has already been described [3] and in the present paper we propose a brain version and provide the neural circuitry for that.

Suppose that two communicating parts of the brain, *A* (Alice) and *B* (Bob), must verify pairs of *N*-long bit strings via a slow communication channel within the brain. We represent the possible bits in the strings by $2N$ partially overlapping random neural spike sequences (neuro-bits). Via the brain wiring, Alice and Bob have the ability to access these neuro-bits and use them as a reference signal. Then a *hyperspace neural signal* is generated by making the pairwise XOR function of the *N* neuro-bit values of the strings at each clock step. For example, comparing only 83 time steps of the hyperspace signals at Alice and Bob's side provide an error probability of less than 10^{-25}, i.e., a value of the order of the error rate of regular computer bits. Therefore it is enough to create and communicate a small number of signal bits through the information channel. It is important to note that this error probability is independent of the length *N* of the bit string. The neural circuitry to carry out this protocol will also be shown.

Generalizing this method for the brain may show how intelligence makes reasonable decision based on a very limited amount of information. Our results provide a functional explanation why spike transfer via neurons is usually statistical with less than 100% success rate.

References

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