

Influence of channel noise and metabolic cost on neural information transmission

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Neural processing is metabolically expensive. In humans, sodium pumping in the brain accounts for 10% of resting oxygen consumption. Since the energy available to the brain is limited, we assume that nervous systems evolved towards energy efficient computation.

Most cell signals are generated by discrete stochastic events (e.g. the binding of a ligand molecule by a receptor; the opening or closing of an ion channel). The reliability of neural signalling, and hence the quantity of information transmitted, increases with the number of stochastic units N . But so does energy usage (e.g. synthesis and transport of transmitter molecules, flow of ionic current through channels). Consequently, the signalling of such a system is subject to a tradeoff between information transmission and energy consumption.

We have explored the relationship between information transfer and energy usage in stochastic signalling systems by analysing the generation of analogue electrical signals by sodium and potassium channels. We find an optimum number of ion channels that maximises energy efficiency (Fig. 1) and depends upon the relative magnitude of the basic cost of constructing and maintaining the system. The higher the ratio of basic cost to signalling cost, the larger the optimum number of channels (Fig. 1).

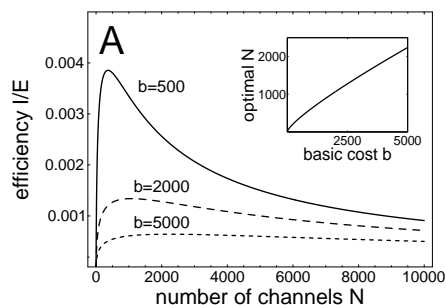


Fig.1: Efficiency (defined as the ratio between information transfer I and metabolic energy E) plotted against the number of ion channels, N , for three different basic costs, b . I is calculated in bits and E (in arbitrary units) is proportional to N . The optimal N increases with b and the efficiency curves become broader.

The efficiency of information transfer also depends on the choice of the input distribution (here defined as the distribution of probabilities for a channel to be open). We find that energy efficient input distributions favour inputs that yield very low and very high probabilities that channels are open, and tend to restrict the use of large inputs. In conclusion, we have demonstrated tradeoffs between information and energy that are basic to molecular signalling. If energy usage is a significant constraint, these tradeoffs will influence the numbers of signalling molecules and synapses used by neurons and the manner in which these mechanisms represent information.

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