Microscopic computation by biochemical systems

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Information thermodynamics is a relatively recent field that attempts to understand the physical basis of computation. An important emphasis of work in the field is placed on feedback processes, entropy production in stochastic systems and copying processes. While this is valuable, it is often unclear how this relates to theoretical computer science.

In this talk, I will attempt to clarify this connection. I will focus on computation by stochastic systems, more specifically Markov Chains. In the first part of the talk, I will define in what sense stochastic systems compute. As a model system, I will consider biochemical computers. These have recently attracted significant interest as an important type of microscopic computation. Examples are biological systems, such as kinetic proof-reading, sensing, DNA copying or translation. I will propose the concept of entropy driven computer (EDC) as a general formal model of chemical computation. I will find that EDCs are subject to a trade-off between accuracy and entropy production. Similar trade-offs are frequently found in biological computations, for example in gene regulation. However, these biological systems usually also display a trade-off in time in the sense that the speed of the computing can only be increased of the noise is also increased or more energy is used for the computation. EDCs do not show this time-trade-off. The latter only arise when it is taken into account that the observation of the state of the EDC is not energy neutral, but comes at a cost. I will discuss the significance of this conclusion in relation to biological systems and in relation to microscopic computation in general.

The performance - cost trade-offs of EDCs mean that deterministic computation is difficult to achieve in those systems at finite cost. However, we know that deterministic computers do exist. In the second part of the talk, I will then extend the discussion and ask under which conditions systems are able to compute deterministically. I will relate deterministic computation to EDCs and calculate minimal resource requirements for a deterministic computation.

[l] D. Chu, JTB **414**, 137 (2016).
[2] D. Chu, arxiv1612.07184.
[3] D. Chu, Sci. Rep. **6**, (2016).