NOTES ON COMPUTATION AND INFORMATION PHYSICS IN BIOLOGICAL SYSTEMS

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Consider a system that undergoes a transition from state i to state j, $i \to j$, such that the entropic cost of such a transition (if done in an irreversible manner) is $\Delta S \geq k \ln(2)$, where k is Boltzmann's constant, according to Brillouin's inequality [1], or Landauer's principle [2]. Furthermore, then the associated energetic cost (via heat released by the system) to the erasure of one bit would be given by $\Delta Q = kT \ln(2)$, where T is the temperature at which the computation (or state transition for that manner) is performed. Also from [1] and from what was said in [3], we can associate the energetic cost of a certain state transition with an error probability η (can also be interpreted as an error of measurement performed by such system), such that $\Delta Q = kT \ln(1/\eta)$. Adding to that, heat released over an arbitrary transition can also be represented as $\Delta Q = kT \ln(\Omega)$, where Ω is the number of states the system is able to transition into (and if state transitions are equally probable). If state transitions are not equally probable, then $\Delta Q = -kT \sum_i p_i \ln(p_i)$, where p_i represents the state transition probability from the current state to an i^{th} state. For a certain transition then, η will be minimized if there is higher energy dissipation, or if the transition is performed in a slower manner, $v \to 0$.
As for the matter of biological systems, presumably neither $\eta \to 0$ (1) or $\Delta Q \to \infty$ (2) can be achieved. For (1) the apparatus that leads to the respective measurement (with low η) would presumably be too costly, and systems with low η would be easily exploited given that their input-output map is a "given" (in the sense of having low stochastic character). As such competitor systems would be pressured into evolving apparatus that could reasonably predict the respective input-output map, and there would be a convergence to an evolutionary equilibrium, in terms of stagnation. Emergent systems would be

pressured to have minimaxing strategies, such that they could predict to a certain level, without being terribly predictable.
As for (2), it wouldn't presumably be achieved given the resource scarce conditions under which these systems emerge and evolve. Correspondingly, there are also time-constraints and $v \to 0$ would be under negative evolutionary pressure.
Regarding scaling metabolic rates, biological systems seem to have metabolic output given by the following expression:

$$\Delta Q \propto m^{\alpha}$$

where is m the system's mass, and α a factor that tends to be smaller than 1 (typically $\alpha = 3/4$) [4, 5, 6]. As a first interpretation, we would perhaps presume that (in mass-specific terms) larger systems have a lower cost on information processing, or that they have a decreased need for information processing. We can also see this, as an emergence of top-down constraints, with the associated decrease of mass-specific Ω.

References

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