SFI TRANSMISSION

COMPLEXITY SCIENCE FOR COVID-19

STRATEGIC INSIGHT: **The concept of the extended phenotype provides a way to circumvent Landauer's bound.**

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Landauer's bound is a deep principle of physics, relating information-processing with the expenditure of energy. Loosely speaking, it says that any physical system must produce more heat if it implements more computation. Among other things, this means that even if you were to use the technology of some far-future civilization of demigods to build yourself a new laptop, that laptop would still generate heat when it runs.

While Landauer's bound cannot be avoided, it can be circumvented. To see how, note that the bound concerns physical systems that *perform a computation themselves*, and that *expend energy themselves*. But what if you get some other system to do those things on your behalf?

Getting outside systems to do your bidding this way is a well-established phenomenon in biology. One way it is often formulated is by extending the concept of a biological "self" from just your physical body to all those aspects of the surrounding environment that you can influence or control. This perspective on what the "self" is in biology, tracing back to Richard Dawkins, is known as the **extended phenotype**.

There are many versions of the extended phenotype. Some of them concern scenarios in which one gets a *non-living* outside system to do one's bidding. A canonical example of this type of extended phenotype is the dirt mounds that termite colonies make and then control, in order to stay alive. Another example of this type of extended phenotype is the wearing of clothes by a human being in order to stay warm.

As Dawkins emphasized, the concept of "self" can also be extended from your physical body to include aspects of *other biological systems* that you can influence or control. An example of this second type of extended phenotype arises when crickets infected by hairworms commit suicide by drowning — behavior that is essential to the reproductive cycle of the hairworm infecting it. In this example, the cricket and its behavior are part of the extended phenotype of the hairworm.

The way this relates to Landauer's bound is that, if you happen to have a biological system around, it's often far easier to get *it* to perform computation and expend energy on your behalf rather than do those yourself. In other words, the concept of the extended phenotype provides a way to circumvent Landauer's bound.

There are many examples of this in nature. A tongue-in-cheek example is that in which the physical system "getting biological systems to do its bidding" is just a molecule: caffeine. Coffee, after all, wakes up the person drinking it. It makes that person engage in many computations that coffee cannot do itself, and makes them expend lots more energy than the coffee can expend itself. So, strictly speaking, coffee "gets biological systems to perform computation on its behalf, and to expend energy on its behalf," basically by waking someone up. In this sense, a waking human is part of the extended phenotype of coffee. (Thanks to Josh Grochow for discussion of this example.)

In more conventional examples of the extended phenotype and Landauer's bound, the controlling system is living, not just a molecule. An example of this arises in social systems. After all, a leader of a social group "gets other systems to perform computation on its behalf, and to expend energy on its behalf." Leaders behaving this way can be found in social systems ranging in size from small groups of friends to (most) large governments.

In a more sobering vein, there are other systems, lying halfway between single molecules and leaders of social systems, that also "get others to perform computation on its behalf, and to expend energy on its behalf." In particular, a virus can be viewed this way.

"Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)," to give it its full name, is a small package of molecules: basically, just an RNA molecule, surrounded by several protein molecules. Any single such package of molecules hijacks human cells to make more such packages of molecules. By doing that, the virus gets the human cell to expend a huge amount of energy (involved in duplicating the virus many times over) and to perform an elaborate computation (namely, the biochemical computation involved in that manifold duplication). Both of those expenditures are far beyond what the virus could do itself.

So each single virus can be viewed as a system that circumvents Landauer's bound by using its extended phenotype to duplicate itself. In fact, COVID-19 also circumvents Landauer's bound on a far larger scale. Not only does a single SARS-CoV-2 virus hijack an individual human cell, getting that cell to do its bidding; a SARS-CoV-2 *population as a whole* also hijacks the entire immune system of the host, inducing that infected host to, for instance, cough and sneeze (a huge energy expenditure), thereby spreading the virus population to entirely new hosts (a process which involves all kinds of information-processing by the surrounding atmosphere, surrounding humans, etc.).

So at the population level as well the individual level, SARS-CoV-2 circumvents Landauer's bound by using its extended phenotype.

Evil as SARS-CoV-2 might seem, we scientists who investigate the fundamental relationship between computation and energy expenditure can't help but look at it with awe.

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