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POINT OF VIEW

A Mechanistic Model of Meaning

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Ever since the scientific revolution, physics has been the ‘queen’ science and biologists have been split into twp opposite camps, one in favour and one against adopting its paradigm, a view that has become known as *mechanism*. That paradigm, however, has undergone at least three major changes in the last few centuries, and we need to keep them well in mind if we want to avoid misunderstandings.

The first version of mechanism in biology was the Cartesian doctrine that “*the body is a machine*” and that the clock is its model: *“A healthy man is like a well functioning clock*—wrote Descartes—*and an ill man is like a clock that needs repairing”*.

The mechanical concept of nature spread very quickly in 17th century Europe, but not without conflict. Opposition came particularly from a new science that was slowly emerging from the night of alchemy and that regarded the human body essentially as a seat of chemical reactions. The heirs of the alchemists were determined to leave magic behind, but had no intention of accepting the ‘mechanical’ view of nature, and one of chemistry’s founding fathers, Georg Ernst Stahl (1659–1731), launched an open challenge to mechanism. He claimed that organisms cannot be machines because what is taking place inside them are real transmutations of substances and not movements of wheels, belts and pulleys.

The arguments of the chemists did have an impact and forced mechanists to change the very concept of living machine. In the course of the 18th century, the view that organisms are *mechanical machines*, gradually turned into the idea that they are *chemical machines.* This change of perspective went hand in hand with the development of the steam engine, and that machine became the new model of biology. In the 19th century, furthermore, the study of the steam engine was pushed all the way up to the highest level of theoretical formalism, and culminated with the discovery of the first two laws of thermodynamics. The result was that any living system came to be seen as a *thermodynamic machine*,

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i.e., as a chemical machine that must be continuously active in order to obey the laws of thermodynamics.

This was the second version of mechanism in biology: the idea that organisms are *thermodynamic machines* and that life consists in an exchange of *energy and matter* between them and the environment.

At the beginning of the 20th century, the rediscovery of the laws of Mendel led Wilhelm Johannsen to make a sharp distinction between the visible part of an organism (the *phenotype*) and the invisible part that carries its hereditary instructions (the *genotype*). Johannsen concluded that any living being is a dual entity, a synthesis of two complementary realities. This idea was largely ignored, at first, but a few decades later the computer made it immediately comprehensible. The *phenotype-genotype* duality was a *hardware-software* distinction and became the prototype description of any organism. The model of the living system changed again and became the computer (more precisely, the self-replicating machine described by John von Neumann in the 1940s).

This was the third version of mechanism in biology: the idea that living systems are *information-processing machines* and that life consists in a continuous exchange of *energy, matter and information* between them and the environment.

In the 1960s, the discovery of the genetic code provided the potential for a fourth version of mechanism. A code is based on *meaning*, and the existence of a genetic code in every cell implies that meaning is as necessary as information to describe living systems. But biology did not take that road. It embraced an *informational mechanism* and did not go any further. A mechanism based on information *and* meaning, i.e., a *semiotic mechanism*, is the fourth expression of mechanism in biology, but its theoretical potential is still out there, waiting to be explored. To this purpose, we need to think again our basic paradigm, so let's go back to the beginning and ask ourselves: *what actually is mechanism?*

One of the expressions that best catches the spirit of mechanism is John Maynard Smith's statement that *"We understand biological phenomena only when we have invented machines with similar properties"*.

In fact, 'understanding' something means explaining it with a model that we are familiar with, and a machine gives us an immediate sense of familiarity. When we see it working before our eyes, we feel that we 'know' it. Actually, we do not even need to build a machine to get this feeling. A description is enough, and so a machine is often just a *model*, or even an *algorithm*. One of the most famous machines of all times was built by Turing with just pencil and paper.

A model, furthermore, does not necessarily have a mathematical form. Natural selection, for example, is a mechanistic model which is entirely expressed in words. The important point is that the model has the *logic* of a machine (i.e. that it delivers the same sense of familiarity that we get from a real functioning machine). Mechanism, in short, is the view that scientific knowledge is obtained by building machine-like models of what we observe in nature. Let us briefly summarize it.

(1) Mechanism is not *reductionism*, because a machine is a machine not when it is taken to pieces but when it is put together into a working whole.

(2) Mechanisms is not *determinism*, because it is more general than classical physics (quantum theory is mechanism, and so is non-equilibrium thermodynamics, chaos theory, complexity theory, and the like).
(3) Mechanism is not *physicalism*, because it is not limited to physical quantities (natural selection, the Turing machine and Godel's theorem are mechanistic models that are not based on physical quantities).
(4) Finally, and most importantly, mechanism is made of models and models do not coincide with reality (*"the map is not the territory"*), which means that mechanism is intrinsically incomplete and continuously evolving.

Mechanism, in short, is virtually equivalent to the scientific method. The difference is that the hypotheses of the scientific method are replaced by models, i.e., by sets of concepts that must fit together into fully operational working systems.

Ever since it first appearance, at the beginning of the scientific revolution, mechanism has been highly effective in accounting for particular aspects of Nature, and at the same time it has shown an extraordinary ability to change in the face of adversity. The first mechanistic model of the body was the clock-machine, then came the steam-engine-machine, and after that the computer-machine. Which amounts to saying that mechanism has introduced in biology first *mechanical energy*, then *chemical energy*, and finally *information*.

Now we face the challenge of introducing in biology the last frontier, the concept of *meaning*, and once again we hear that mechanism is not enough, that we need something completely different. Which maybe true, of course, but mechanism remains our best chance to find out what makes living systems tick, so let's see how far we can go with it.

Let us start from the fact that the origin of the genetic code is what we need to explain in order to account for the origin of meaning in organic life. Let us also keep in mind that genes and proteins are manufactured molecules, so it was molecular machines that brought them into existence. The simplest molecular machines that appeared on Earth were *bondmakers*, molecules that could stick monomers together at random, and slightly more complex were those that could stick them together in the order provided by a template. They were the first *copymakers*, the molecular machines that started populating the Earth with a potentially unlimited number of copied molecules, in particular of nucleic acids.

That event was the very first beginning of life on Earth, because the copying of nucleic acids leads in the short run to heredity and in the long run to natural selection. Heredity and natural selection, in other words, are the result of a copying mechanism that is extraordinarily simple.

But there is more to life than heredity. There is metabolism, the actual building and re-building of the cells and of the bodies of all creatures that makes up what the living world actually is. And here things are much more complicated, because the crucial molecules of metabolism are proteins and proteins cannot be copied like genes. They are manufactured by huge molecular machines called *ribosomes* according to the rules of the genetic code, and even the simplest apparatus for their synthesis requires dozens of different molecules and an extremely sophisticated system of interlocked operations.

The origin of genes, in short, can be explained by a relatively simple mechanism, but the origin of proteins demands an apparatus whose complexity is almost beyond imagination. That is the *hard problem* of the origin of life. We can account for organic information, but how do we account for the organic meaning of the genetic code? Another obstacle is that the origin of the genetic code took place almost four billion years ago and has left no trace in the fossil record. How can we hope to understand what happened?

One can be forgiven for saying that we have no chance, but that is not completely true because the genetic code was not an isolated exception. There have been many other organic codes in the history of life, all the way up to the codes of language, and this does make a difference because we can look for what the codes have in common, not for their individual features. More precisely, we can look for the 'logic' of coding: how can a community of natural objects organize itself in such a way that a code appears into the system?

This remains a formidable problem, but it has a logical structure and it is much more accessible than the historical problem. So much so that the first step, surprisingly, has already been taken. It is described in this very issue, in the paper entitled "Introducing dynamics into the field of Biosemiotics" by Joachim De Beule, Eivind Hovig and Mikael Benson.

It is only a model, of course, but the impression that one gets is beautiful. It gives us the feeling that the hard problem can, after all, be solved. And it is a *mechanistic* model of meaning. Mechanism truly is a never ending search for scientific truth. It does not give us the comfort of a belief system, but if we want to *understand* life it is still the best tool we have.