The modal structure of biology

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Abstract

Science can elucidate not only what is actual, but also what is possible, impossible, necessary, or contingent. Laws of nature do not merely describe regularities in nature; they allow us to predict the behaviour of various systems, and to offer counterfactual accounts of what would have been the case, had certain conditions obtained. The existence of objective modal structure in the world is arguably required for scientific realism (Berenstein & Ladyman 2012).
Within nomological modality, it is generally accepted that physics has the broadest scope of applicability, such that the laws of physics apply to the objects of other sciences as well. For example, biological organisms are just as subject to physical laws as inanimate objects. More restricted modalities are typically defined in terms of a domain-specific restriction of either physical or metaphysical modality. For example, Kment states that "biological necessity can be defined as the property of being metaphysically (or perhaps nomically) necessitated by the basic principles of biology" (2006), and Gravtol argues that "one can take biological laws to restrict possibilities left open by physical laws" (2024).

Framing biological modality as a kind of restricted modality based on biological laws, however, might seem strange to philosophers who think that there are no such laws, that biological generalisations lack nomic necessity (Beatty 1993), or that they are, at best, 'frozen accidents', which nonetheless support some counterfactuals (Strevens 2008). Here I argue that, on the contrary, biology has a rich modal structure that includes: physical necessity, biological necessity, possibility, probability, laws, and a variety of possibility spaces that evolve over time and interact with historical contingency in complex ways.

Consider an organism. Some of its feature are explained by physical necessity: they could not have been different, due to physical laws. For example, an organism cannot do work without expending free energy and dissipating heat. Although physical necessity is, of course, physical, I argue that since it plays an explanatory role in biology, it is also part of the modal structure of biology – it is in fact a fundamental part of it. Ladyman and Ross claim that "(f)rom the point of view of those engaged in special science activity, fundamental physics gives the modal structure of the world" (2007: 288), but various areas of physics provide modal scaffolding for biology, including thermodynamics, fluid mechanics, and condensed matter physics.

Other features of a given biological system are due to biological necessity, understood as a restriction of physical possibility to what is compatible with life. For example, it is physically possible for all the components of a cell to be located on the outside of the cell membrane,

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but this spatial arrangement is not compatible with life. Viability explanations (Wouters 1995) and constraint-based generalities (Green 2015) are an important class of explanations that are about biological necessity.

For many other features of an organism, it is both physically possible and compatible with life for them to have been different from what they are; however, for some of those features, it was *overwhelmingly likely*, given how natural selection works, that they would have been as they are (or with only minor variations), because all possible alternatives would have been much less efficient at carrying out the relevant function under selection. Although they are strictly speaking contingent, we should not expect life to deviate from these solutions, and as such they do support counterfactual reasoning. Other features, however, could easily have been different, and are the way they are mainly due to historical contingency, including initial conditions, plus whatever physical, chemical, and/or biological laws determine the functioning of the trait in question, plus natural selection. Most features lie on a continuum of likelihood.

Although biological possibility is a restriction of physical possibility, instead of one space of biological possibility, there are multiple biological possibility spaces, indexed to different organism, lineages, and even kinds of life, and they are not static but also evolve over time. The broadest sense of biological possibility is what is possible for life in general – this space of possibility is only restricted by what is both physically possible and compatible with life. Astrobiology and synthetic biology are engaged in trying to determine what is biologically possible in this sense.

Once a particular kind of life has originated, however, some possibilities are closed off – they are no longer possible for *this* life. For example, once life is on a carbon-based biochemistry pathway, it could never change to a silicon-based biochemistry instead, even if that option had been possible at the start. The past evolutionary history and present features of the organisms in a lineage can determine its *evolvability*, understood as differential access to biological possibility spaces. In order for some feature to evolve, it has to be not only biologically possible, but accessible from within an existing lineage, considering that evolution is gradual, and that all intermediate stages must be viable. This means that, in some cases, "you can't get there from here".

Finally, another aspect of biological modality has to do with what is biologically possible for a particular organism in a particular spatio-temporal location. This might include its developmental possibilities (which change over time as the organism must actually take one developmental pathway, thus closing off alternative possible ones), physiological possibility, and even behavioural possibility.

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