Explanation in biology[*]

Arno Wouters, Department of Philosophy, Erasmus University Rotterdam, Rotterdam, The Netherlands, wouters@fwb.eur.nl

Synonyms

Definition

An explanation of a characteristic of a system is an account of why that system has that characteristic

Characteristics

Explanations in biology, unlike those in physics, rarely proceed by filling out the parameters in mathematical equations (laws) that describe the general characteristics of the relevant form of organization. With the notable exception of population genetics and theoretical ecology, biologists typically employ mechanistic, functional and historical strategies of explanation, rather than mathematical ones. To some scientists this is a sign of the immaturity of biology, perhaps resulting from the difficulty to take into account the extraordinary high number of parameters and variables relevant to the phenomena that interest biologists. Structuralist biologists such as Brian Goodwin (e.g. 1994) have pointed to the dominance of gene-centered and historical approaches as the main source of immaturity. They hope that in the future more research, more data, more computational power, better mathematics and, above all, more insight into the proper way of explaining in the natural sciences and more willingness to pursue the structuralist strategy will enable what is thought to be a more scientific approach.

Many others reject the view that the minor role of general laws in biological explanation is a sign of its immaturity. They argue that the objects of study in biology have characteristics that justify approaches different from those suitable in physics. One such view points to the process by which life gets its shape: evolution by natural selection. For example, the evolutionary biologist Ernst Mayr (1904–2005), one of the founding fathers of the modern synthesis, argues that it makes sense to ask why-questions in biology but not in physics and chemistry (e.g. Mayr 1997, Ch. 6). The reason is that organisms owe their characteristics to their history, whereas history is not important to the characteristics of physical and chemical systems. So whereas physics and chemistry must limit themselves to how-questions, biologists should address why-questions in addition to how-questions. Within biology how-questions and why-questions are, according to Mayr, the subject of two 'largely separate

[*] To appear in: Dubitzky, Wolkenhauer, Cho & Yokota (eds.) *Encyclopedia of Systems Biology* (Springer, 2012).

fields': functional biology and evolutionary biology, corresponding with two modes of explanation: functional explanation and evolutionary explanation. Functional explanations answer how-questions by describing the operation of mechanisms. Evolutionary explanations answer why-questions by relating the evolutionary history of those mechanisms. Both kinds of explanation are legitimate and needed to understand the living world, but evolutionary explanations provide the distinctive biological perspective.

Whereas Mayr seeks the justification of the biologist's concern with why-questions merely in the importance of history for understanding the characteristics of organisms, many philosophers (e.g. Dennett 1995) refer to the specific character of that history as being a selection history. Unlike physical objects, organisms have the character they have because ancestral variants with those characteristics were favored over variants with other characteristics. For that reason in biology, but not in physics and chemistry, the answer to the question how a certain characteristic is produced must involve an answer to the question why (e.g. for what effects) that characteristic was favored in the selection process.

In my view, attempts to justify types of explanation in biology that differ from explanations in physics and chemistry by appeal to the importance of history for understanding organisms or by appeal to the special character of that history are unsatisfactory. Such attempts take the importance of history for granted, whereas they should explain it. Moreover, they fail to address the many differences between *functional* biology, and physics and chemistry (see Fox Keller 2002 to get a feeling for the weirdness of mechanistic explanation in biology in the eyes of a theoretical physicist). The most notable differences are a preference for mechanistic models that visualize interactions over abstract mathematical system descriptions (i.e. equations that do not bear an obvious relation to the physical properties of the parts of the system), appeal to role functions to explain how mechanisms work and the appeal to advantages and requirements to explain why a certain mechanism has the characteristics it has.

A better justification starts with the observation that organisms are highly organized (see also the essay on organization): their capacities and characteristics critically depend not only on the characteristics of their parts but also on the spatial arrangement of those parts and on the order and timing of their activities. Explanations in physics and chemistry are typically aggregative: they derive the behavior of a system (such as the behavior of a volume of gas as described by the Boyle-Charles law) by aggregating the behavior of the parts of that system (the molecules of which the gas is composed as described by Newton's laws of motion). As philosopher William Wimsatt (e.g. 2007, Ch. 12) has argued, very few system properties are aggregative under all possible decompositions of a system into parts. The list is pretty much exhausted by the quantities that appear in conservation laws: mass, energy, momentum and net charge. All other system properties are more or less organized in the sense that they break down under at least one of the four conditions for aggregativity identified by Wimsatt (invariance under rearrangement and substitution, size scaling, decomposition and re-aggregation, and linearity). By carefully choosing a decomposition, by limiting explanations to certain forms of organization, and by introducing idealizations and approximations (in the description of the system and in the derivation of the system's behavior) the power of aggregative explanation can be expanded immensely. However, if a system is very highly organized there comes a point where aggregative explanation is no longer possible and where the system's organization must be taken into account.

In biology this is done by viewing organisms as mechanisms (mechanism) for being alive (Wouters 2005). For the purpose of this essay, a mechanism for a certain behavior can be defined as a complex system that produces that behavior by the organized interaction of its parts (cp. Glennan 1996; Machamer et al. 2000). Because the behavior of a mechanism results from its organization, a mechanism can be seen as a solution to the problem of how to organize the parts and their interaction in such way that this behavior is generated. Note, that this problem need not be *experienced* by the mechanism or some other system. The difficulty (that is, the amount of organization needed) to produce or maintain that behavior in the circumstances in which it occurs suffices to talk of problems. As George Cuvier (1769–1832), the founding father of functional zoology, already noted, the very existence of organisms means that they have solved the problem of how to stay alive (cf. Reiss 2009). Organisms exists far from thermodynamic equilibrium and can exists only by actively maintaining their organization (Prigogine and Stengers 1984). To understand how this form of existence is possible a combination of explanations of four kinds must be employed, as many biologists have recognized (e.g. Tinbergen 1963): mechanistic explanation, functional explanation, developmental explanation and evolutionary explanation.

Mechanistic explanations (explanation, mechanistic) explain how the behavior of a mechanism arises from the properties of the parts, their interaction and the way in which this interaction is organized. Biology's functional perspective glues explanations of different mechanisms together by viewing those mechanisms in terms of their role in maintaining the state of being alive (that is in terms of their biological role). The different organ systems have specific roles in bringing about the living state. Each organ system consists of organs with specific roles in bringing about the properties of the organ system that enable that organ system to perform its role in the maintenance of the living state. Each organ in turn is divided into subsystems, each with a specific role in bringing about the properties relevant to that organ's biological role. And so on, until a level is reached in which the relevant system properties arise out of unorganized components. Attributions of biological roles (often called 'function ascriptions') (see function, biological) situate the different mechanisms in this encompassing hierarchical organization, making it possible to see different mechanistic explanations as part of the larger project to understand how organisms are able to stay alive. Attributions of biological roles are, hence, the key to explanation in biology.

The very fact that the behavior of mechanisms (including organisms) results from the *organization* of their parts (in addition to their composition) means that in order to understand a mechanism it does not suffice to explain how it works. The mechanism's solution to a certain problem need not be the only possible solution to that problem. On the other hand, by definition, not any form of organization will solve any problem. So in order to understand a mechanism one must not only explain how its organization results in a certain behavior (as is done in mechanistic explanations), but also why that mechanism's organization solves the problem whereas other forms of organization (often called 'designs') do not. This opens up the possibility and the need to explain why a mechanism has the characteristics it has on the basis of the requirements it has to satisfy: the constraints imposed on it by the problems it must solve, the other characteristics of that mechanism and the conditions under which it works. This is what functional explanations (explanation, functional) do.

Furthermore, because, by definition, one does not get a mechanism by throwing its parts together, the question of how the organization that solves the problems arises in the course of time needs consideration too. As became clear in the wake of Charles Darwin's theory of evolution, in the case of living mechanisms the answer requires a two staged explanation. Developmental explanations (explanation, developmental) explain how the organization arises in the course of individual development. Evolutionary explanations (explanation, evolutionary) explain how the machinery to develop the required organization arose in the course of evolutionary history.

So, the view of organisms as solutions to the problem of how to maintain the living state provides a unifying perspective in biology that explains and justifies the importance of the four kinds of explanation employed in biology, the relation between those explanations and the main differences between biology on the one hand and physics and chemistry on the other.

Cross-references

Explanation, developmental
Explanation, evolutionary
Explanation, functional
Explanation, mechanistic
Function, biological
Mechanism
Organization

References

Dennett DC (1995) Darwin's Dangerous Idea. Simon & Schuster, New York

Fox Keller E (2002) Making Sense of Life. Harvard University Press, Cambridge

Glennan SS (1996) Mechanisms and the Nature of Causation. Erkenntnis 44:49–71
Goodwin BC (1994) How the Leopard Changed Its Spots. Phoenix Books, London
Machamer PK, Darden L, Craver CF (2000) Thinking About Mechanisms. Philosophy of Science 67:1–25
Mayr E (1997) This is Biology. Harvard University Press, Cambridge
Prigogine I, Stengers I (1984) Order Out of Chaos. Heinemann, London
Reiss JO (2009) Not by Design: Retiring Darwin's Watchmaker. University of California Press, Berkeley
Tinbergen N (1963) On Aims and Methods of Ethology. Zeitschrift für Tierpsychologie 20:410–433
Wimsatt WC (2007) Re-Engineering Philosophy for Limited Beings. Harvard University Press, Cambridge, Ma
Wouters AG (2005) The Functional Perspective of Organismal Biology. In: Reydon TAC, Hemerik L (eds) Current Themes in Theoretical Biology. Springer, Dordrecht, pp 33–69