



On Connections between Properties in Biology – How we Learn about Order in Organisms

Manfred Drack^{1,2,3*}

¹ *Evolutionary Biology of Invertebrates, Institute of Evolution and Ecology, University of Tübingen, Auf der Morgenstelle 28, 72076 Tübingen, Germany*

² *Bertalanffy Center for the Study of Systems Science (BCSSS), Paulanergasse 13/5, 1040 Vienna, Austria*

³ *Department of Theoretical Biology, University of Vienna, Althanstraße 14, 1090 Vienna, Austria*

ABSTRACT Our knowledge in biology and especially about order and organisation in organisms is based on observational and experimental evidence. This evidence is used to derive connections among properties (parameters, traits, functions, etc.) – a central goal of science. Certain such connections are discussed here. Often in biology, (1) correlations are pointed out, whereby properties that appear or change simultaneously are connected. Infrequently, the connection has a (2) causal basis; examples can be found in physiology. (3) Ad hoc connections, which are based on plausible narrations about adaptations, can be found in evolutionary biology. The (4) morphological connections are again of a different sort because they are based on hermeneutics. (5) Connections that are based on parallel or analogous appearances are exemplified by computer simulations. They are contrasted by (6) connections through building, where also the mechanisms that produce a phenomenon or function are similar to those in the natural system. All the connections are used to derive explanations and predictions. Due to the different basis of the connections, the derived explanations and predictions differ with regard to their degree of certainty. Hence it is useful to consider the differences of the connections. Clear distinctions between the types of connections (and their basis) can help to reduce the risk of misunderstandings.

KEYWORDS knowledge, organism, system, explanation, prediction

1. Introduction

A goal of science is to find constant relationships or connections between different phenomena or properties. According to Ernst Mach, science strives for connections between appearances [*Zusammenhang der Erscheinungen*] (Ritter and Gründer 1998:1144). Such constant connections are the basis for logically inferring explanations and predictions (Carnap 1995:3–18). An instance of such connections are mathematical equations, for example those that deal with thermodynamics. Here, there is a connection between temperature and pressure, among others. If the temperature of a closed gas-filled vessel is increased, the pressure also increases. Such instances are not restricted to physics. Biologists also “connect” different parameters or, more generally, properties. The properties that biology deals with are of a broader range than those of physics, and include traits.

* E-mail address: manfred.drack@uni-tuebingen.de

This open-access article can be downloaded from www.systema-journal.org

ISSN 2035-6991 Bertalanffy Center for the Study of Systems Science www.bcsss.org

© Author ; Licensed under a [Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License](https://creativecommons.org/licenses/by-nc-nd/4.0/).

In the following, six ways of connecting properties in biology are discussed along with the knowledge on which they are based. Explanations and predictions rely on the different types of connections. The degree of accuracy of the connections is also reflecting the accuracy of the resulting explanations and predictions. This investigation provides a clearer overview of different connections and thereby of the reasonings behind many biological arguments and their certainty.

The motivation for such a systematisation can be illustrated by the following quote of a systems biologist: "Although clustering analysis provides insight into the 'correlation' among genes and biological phenomena, it does not reveal the 'causality' of regulatory relationships" (Kitano 2002). Here, correlation and causation are explicitly mentioned. Upon closer examination, other connections between parameters can also be found in biology. This leads to different answers to the question: Where do you know that (connection) from? In the following, six types of connections, and their empirical (observation and experiment) basis, are distinguished.

2. Correlations

Numerous connections in biology are based on statistical correlations. One example is growing clones of a plant at different temperatures and then measuring plant height at a specific point in time. In this case there is probably a positive correlation between temperature and height. The reasons for such a correlation remain unclear when knowing only that there is a connection of the two parameters. Clearly, physiological arguments support the influence of temperature on height; they also point out that the influence goes from temperature to height and not vice-versa. Statistics alone would not allow such a conclusion: only knowing about a correlation provides no insight into which parameter influences the other, if at all.

The following example should serve to clarify this point: It is probably safe to say that in humans the number of white hairs correlates with the number of wrinkles on the skin. The argument that one influences the other is problematic. It is more likely that the two do not influence each other, but rather that a third process influences both the number of white hairs and number of wrinkles.

Another example for connections with correlation is the "gene for"-connection. Newspaper headlines typically indicate such short-cut connections when pointing out that a gene "responsible" for some illness has been found. Such connections can be based on statistics that attempt to link certain genes or gene expressions with certain properties of the organism. How this actually works, i.e. how the gene produces the property on the organismic level, remains unclear.

The term correlation refers here to a relationship between two properties that was determined with statistical methods. This is an inductive approach and involves all the problems related to induction. Mistakes in measurement and disturbances of the measured parameters are not always known and can lead to false correlations. Moreover, the interpretation of correlations can easily be misleading.

An example of confusing statements comes from statistical investigations of cardiovascular disease: "A paper in today's Journal of the American Medical Association (JAMA) [Stolarz-Skrzypek et al. 2011] offers the contradictory conclusion that taking in less salt [...] is bad for you."¹

3. Causality

When blood vessels contract, one gets cold feet. This goes beyond a conclusion based solely on correlation. As we know from the Hagen-Poiseuille equation, the volumetric flow rate in a tube is proportional to the 4th power of the radius, given that other parameters such as pressure are kept

¹ See: <http://www.health.harvard.edu/blog/does-eating-less-salt-lead-to-heart-disease-new-jama-study-is-more-wishful-thinking-than-a-diet-changer-201105042533> . Posted 2011-05-04 by P.J. Skerrett, visited 2016-06-26

constant. Accordingly, with a smaller radius the blood flow is also smaller and hence also the heat transported with the blood. The contracted vessels and lower heat transportation are connected by a natural law. This is what such connections have in common and what distinguishes them from mere correlations. Physiology provides many such examples.

The term causality is used in different ways, each with its own problems. It is beyond the scope of the present contribution to go into the details – from Hume² to recent³ in philosophy and in practical applications (Pearl 2000). What is relevant here is the difference to correlations as described above. In the cold-feet-example the smaller radius reduces volume flow and therefore temperature transport. The direction of the connection from radius to heat supply is known. Characteristic for this connection is that reasoning proceeds in a deductive manner involving a law of nature. Connections of this sort are related to the proximate or functional causes, as noted by Mayr (2000:102).

Gene knockout experiments allow inferences to be drawn that go beyond mere correlations. Although the exact mechanisms of how such genes contribute to a property or function on the organismic level may not be known (and cannot be examined with such experiments alone), a type of causal influence is shown when differences occur between manipulated and not manipulated organisms. Hence, such a connection between a knocked out gene and an observed effect is assigned to the type of causal connections in a broad sense.

4. Ad hoc connections

Many connections between adapted traits and the environment to which they are adapted have a mere narrative character. Examples are horns, antlers, and tusks. They were formerly seen as “weapons against predators” and later as “symbols of intraspecific competition among males” (Gould and Lewontin 1979:586). Such adaptive stories rely on plausibility and are exchanged by other stories if deemed necessary. The “explanations” usually stop when they seem to be consistent with the theory of natural selection. This is not very satisfying. The question “what good is a theory that cannot fail in careful study” (Gould and Lewontin 1979:589) points out the problem of the accuracy of such connections between trait and adaptation to the environment. Often, alternative explanations can be offered, with similar persuasive power.

A fundamental logical problem is involved: “If selection is taken as an axiomatic and a priori principle, it is always possible to imagine auxiliary hypotheses – unproved and by nature unprovable – to make it work in any special case [...]” (Bertalanffy 1969 cited in Gould 1978:530). The question arises how to prove the proposed connections, if this is possible at all.

Another problem in this area is that knowledge about adaptations and their ultimate or evolutionary cause cannot be investigated with physical or chemical methods; rather, it has to be reconstructed by means of historical considerations (Mayr 2000:102). This is not to say that all such connections are wrong or even necessarily wrong, but rather that many of them are questionable.

5. Morphological connections

There is a connection between the traits of a particular egg and the traits of the animal that eventually hatches from it. Clearly, no chicken egg will give rise to a crocodile. The leaf of an oak tree looks different than a maple leaf. A particular leaf can therefore be used to infer, e.g., the species

² De Pierris G, Friedman M. “Kant and Hume on Causality”, *The Stanford Encyclopedia of Philosophy* (Winter 2013 Edition), Zalta EN, (ed.), <<http://plato.stanford.edu/archives/win2013/entries/kant-hume-causality>>. Published 2013-12-11, visited 2016-06-26.

³ Schaffer J. “The Metaphysics of Causation”, *The Stanford Encyclopedia of Philosophy* (Summer 2016 Edition), Zalta EN, (ed.), <<http://plato.stanford.edu/archives/sum2016/entries/causation-metaphysics>>. Published 2014-03-19, visited 2011-11-21.

of the according tree. Such reasonings are based on morphological investigations in which the traits at different levels of organisation are connected for a particular species and for higher taxa. The hermeneutic approach in morphology (Riedl 2000:123, 139ff) allows for such connections. The basis of such experience knowledge (*Erfahrungswissen*) is the iterative comparison of structures in one organisational level and the investigation of their relationships to higher and lower levels (supra- and sub-systems) of organisation. This goes beyond induction in the case of a simple correlation because the traits that are found at one level have to be consistent with the higher and lower levels of organisation within the organism and the systematic groups beyond. The reciprocal interdependence among the structures provides a rather safe (though not completely certain) basis of knowledge. Our knowledge about homologies rests largely on morphological investigations. The connections found with the hermeneutic method are the basis for systematics and our reconstruction of phylogeny. The method is also a basis for predictions such as in the egg example above. Nonetheless, it differs from the other bases of predictions discussed. Carnap would consider a morphological statement such as “all ravens are black” (if true) to be a “law of zoology” (Carnap 1995:6).

6. Parallelisms

Certain phenomena or functions in biological systems can be seen in parallel to phenomena or functions produced by engineered systems. Accordingly, the “mechanisms” behind such functions are also sometimes proposed to be similar. In this manner, certain phenomena or functions are connected to particular mechanisms that produce the former. The field of cybernetics provides many examples. Regulating finger movement when picking up a pen is seen as a parallel to feedback mechanisms in engineered constructions that move toward a goal (Wiener 1961:7f). Lateral inhibition in the retina, which allows for increased contrast, is another example (Hassenstein 1977:99ff). A circuit diagram for electrical signals (which we know can produce lateral inhibition) is set in parallel with the arrangement and functions of neurons in the retina – a working hypothesis at the time (Hassenstein 1977:103). Such parallelisms are plausible, yet often not proven. In many cases, alternative mechanisms and therefore alternative explanations can also be suggested for the connections between mechanism and phenomenon or function. Simulations in biology also belong here, e.g. cellular automata or neural networks and other models of dynamical systems. The assumption is that the mechanism is known and modelled correctly. In some cases the mechanisms are clearly distinct, as in early robots, but sometimes it is difficult to determine whether a model is appropriate or not. This gives rise to cases where a function can be described correctly, because the appearing phenomena are similar, but they cannot be explained based on an underlying mechanism. Simulations can, however, be used to find out how things do not work and so serve as a starting point for further investigations.

7. Connections through building

The connections in this section are of the same type as those of the former on parallelisms: connections between mechanisms and phenomena or functions. However, the basis here relies on building a real system which is equal to the natural one. One example is the vesicles that were built in the lab in order to test the hypothesis that mitochondrial ATPase in the membrane is driven by a difference in proton concentration inside and outside the membrane (Weber 2005:369ff). The relevant components of the system (the same as in the natural system) could be brought together *in vitro*, and it was shown that the behaviour was as predicted. This provided a sufficient causal explanation for the function. The claim that the enzyme must be located in the membrane and the hypothesis that ATPase receives the energy from the proton gradient (which was questioned before) were verified. When a built system that has the same function as the natural system also consists of the parts and interactions as *in vivo*, one can feel confident about the knowledge and therefore about

a strong connection. Scientists can also systematically “play around” with the components and determine what fits best to the phenomena in the natural system. The building of a system that resembles the function of the natural system requires a hypothesis about which elements and interactions are necessary for that function. Such a hypothesis can therefore be tested and the arrangement sufficient for an explanation can be examined.

8. Comparison and conclusion

One possible arrangement of the here discussed six different types of connections is shown in the table below. More closely related types of connections – i.e. those found in similar areas of research – are depicted on top of each other. Connections of the correlations- and causality-type exist with regard to traits and functions. Ad hoc connections and morphological connections mostly deal with traits or form. Connections based on parallelism and connections through building mostly deal with functions.

Correlations	Ad hoc connections	Parallelisms
Causality	Morphological connections	Connections through building

The degree of certainty about the connections is lower in the top row and higher in the bottom row. Explanations and predictions based on correlations, for example, are not as certain as those based on causal underpinnings. This is not to say that connections based on correlations are wrong, but rather that they are only a starting point for further investigations on the way to higher degrees of certainty. The ad hoc connections also seem to be rather a starting point. Here, however, the problem arises that historical events cannot be investigated directly, and so our knowledge in such cases can only be of a plausible character. Morphological connections are more accurate, but the underlying method also cannot lead to “safe” knowledge because it is based on probability and induction. Parallelisms can provide useful insights, especially with regard to questions of how something cannot work. Beyond that, models that show similar phenomena as natural systems can be useful for further investigations. This can be the starting point for connections through building; this is an important type on which convincing explanations and predictions are based. The Vico-Axiom is interesting in this regard. Related to it, Kant wrote in a letter to Plücker (26.1.1796 XVI 345, 17): “We rationally understand only that what we can make ourselves.” [“*Denn nur das, was wir selbst machen können, verstehen wir aus dem Grunde*”] (cited after Großheim 1999:354).

The classification discussed here is not meant to be exhaustive. Certain connections made in biology may not fit into this schema. Nonetheless, a vast majority is covered by the six types described here.

9. Acknowledgement

Thanks go to the participants of the annual meeting of the *Deutsche Gesellschaft für Geschichte und Theorie der Biologie* (DGGTB) in Bonn for fruitful discussions. The research was funded by the *Austrian Science Fund* (FWF), grant P22955-G17, and the *German Research Foundation* (DFG) as part of the Transregional Collaborative Research Centre (SFB/Transregio) 141 ‘Biological Design and Integrative Structures’ / project C02 ‘Organism concepts in biology and architecture as the basis for an interdisciplinary synopsis of constructional biomimetics.’.

References

Carnap, R. (1995). *An Introduction to the Philosophy of Science*. Mineolo (NY): Dover Publications.

- Gould, S. J. (1978). Sociobiology: the art of storytelling. *New Scientist*, 80, 530–533.
- Gould, S. J., Lewontin, R. C. (1979). The spandrels of San Marco and the Panglossian paradigm: a critique of the adaptationist program. *Proceedings of the Royal Society B*, 205, 581–598.
- Großheim, M. (1999). Atmosphären in der Natur: Phänomene oder Konstrukte. In: R. P. Sieferle & H. Breuninger (Eds.), *Natur-Bilder: Wahrnehmungen von Natur und Umwelt in der Geschichte*. (pp. 325–365). Frankfurt/Main: Campus.
- Hassenstein, B. (1977). *Biologische Kybernetik*. 5. Auflage. Heidelberg: Quelle und Meyer.
- Kitano, H. (2002). Systems Biology: A Brief Overview. *Science*, 295, 1662–1664.
- Mayr, E. (2000). *Das ist Biologie*. Heidelberg: Spektrum.
- Pearl, J. (2000). *Causality – Models, Reasoning, and Inference*. Cambridge: Cambridge University Press.
- Riedl, R. (2000). *Strukturen der Komplexität*. Berlin: Springer.
- Ritter, J., Gründer, K. (Eds.). 1998. *Historisches Wörterbuch der Philosophie*. Vol. 10. Basel: Schwabe.
- Stolarz-Skrzypek, K., Kuznetsova, T., Thijs, L., et al. (2011). Fatal and Nonfatal Outcomes, Incidence of Hypertension, and Blood Pressure Changes in Relation to Urinary Sodium Excretion. *Journal of the American Medical Association*, 305, 1777–1785.
- Weber, M. (2005). Philosophie des biologischen Experiments. In: U. Krohs & G. Toepfer (Eds.), *Philosophie der Biologie*, (pp. 359–378). Frankfurt am Main: Suhrkamp.
- Wiener, N. (1961). *Cybernetics*. 2nd ed. New York: MIT Press.

About the Author

Manfred Drack

Manfred Drack was trained as a mechanical engineer and studied biology. After conducting research at the Center for Biomimetics at the University of Reading, he received a doctorate from the University of Vienna with a thesis on biomimetics and eco-design. He worked in several projects at the Center for Appropriate Technology of the Vienna University of Technology. Rupert Riedl brought him back to the University of Vienna, where he worked on early system approaches in biology. After one year in Olaf Wolkenhauer's group at the University of Rostock, he was working at the Department of Theoretical Biology, University of Vienna. Now he is at the University of Tübingen, conducting research towards a theoretical framework of biomimetics.