Barton Moffatt "A Reexamination of Biological Information from the Perspective of Practice"
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1. Introduction

Much of the philosophical debate surrounding the concept of information in biology centers on the question of whether or not biological systems 'really' carry information. The criterion for determining if a system "really" carries information is whether or not there is a principled, theoretical account of information that captures the relevant biological usages. Sahotra Sarkar says,

> There is no clear, technical notion of "information" in molecular biology. It is little more than a metaphor that masquerades as a theoretical concept and leads to a misleading picture of possible explanations in molecular biology. (Sarkar 1996, p. 187)

Here, since biological systems do not 'really' carry information, information talk is merely heuristic and philosophically uninteresting. Details of other biological practices that utilize informational concepts are often lost because the debate is too focused on one instance of information talk—genetic information and because biological representations are thought to need a certain kind of philosophical foundation. The problem with this methodology is that it takes the failure of philosophical accounts of information to capture current biological practices as conclusive evidence that informational representations in biology are incoherent. This approach is backwards.

My task is to put practice first and give an account of what biologists mean when they use informational concepts. I argue that many philosophers have put the question of justification before interpretation—putting the cart before horse. We need to know what biologists are doing when they use this term before we try to justify their usage. The standard philosophical approach has been to develop a precise justified account of information and apply it to the biology and conclude that the biologist is conceptually confused when the account does not match the practice. I think that this is the wrong approach.

In this paper, I shift attention from abstract reasoning about information in the philosophical literature to concrete reasoning about informational models in biology. The current debate pays too little attention to the biologically prominent concept of signal. I argue that biologists use the concept of signal to model distinct functional roles in biological systems and not in any of the theoretical senses of information found in the current philosophical literature. For cell biologists, a signal causally indicates the state of a system at a given point and is used in the context of a style of functional explanation generally known as 'causal role function,' in which a mechanism or entity has a function if its behavior explains a contribution to a capacity of interest.

I support this analysis with an example drawn from cell biology and reframe the debate over the significance of informational terms in biology. The focus on signal recasts the debate by highlighting examples of information talk which are central to active research programs in biology. The advantage of looking at these models is that their centrality to biological practice forces us to reconsider the adequacy of a methodology that dismisses biological models because we lack a particular kind of philosophical understanding of them. Standard philosophical accounts of information rely on assumptions appropriate for the needs of philosophers but are ill-suited for capturing biological practice. A contextualized understanding of the role of signal in biological practice allows us to work out from the details of practice to tackle broader philosophical issues. On this view, the significance of information talk in biology hinges more on our understanding of how biologists represent function than on our understanding of philosophical accounts of information.

2. Traditional Philosophical Approaches

Philosophical arguments about biological information are too constrained by traditional philosophical assumptions to provide a satisfactory account of biological information. They tell us as much about how philosophy of science is typically done than about the biological practice. In particular, these arguments assume: 1) that information talk is to be understood in terms of a technical or formal account of information; and 2) that the meaning of the term 'information' alone explains how informational models are applied in the world and 3) that a single account of information must capture all biological concepts. As a result, the suggested analyses of information are unnecessarily narrow. The way to move the debate forward is to abandon these core constraints, which allows for a fresh look at biological information—one that is necessary for understanding the role that informational concepts play in the production of biological knowledge.

The philosophical analyses reviewed here exhibit a particular style of philosophical reasoning. The standard approach is to frame the debate around the question of whether the concept of information can justify a distinction between the role of genes and environments in development. The task of the philosopher is then to assess this question by doing three things. First, clearly articulate different formal (or at least precise) accounts of information. Second, apply this account to the relevant phenomena.

Third, determine if the account supports the distinction between genes and environment. If the account articulated captures the distinction, we have clarified the concept at hand. If not, then we have shown that that concept does not support the distinction. If we have articulated all of the relevant concepts and none of them justify the distinction, we can conclude that no concept can justify the distinction. This style of reasoning is severely constrained.

A shortcoming of this style of reasoning is that it has yet to provide a successful explication of what biologists mean when they use the term information. To date biological information has been analyzed as the reduction of uncertainty [see Sarkar (1996a), Sarkar (1996b), Griffiths and Gray (1994), Griffiths and Knight (1997), Griffiths (2001)], systematic causal connection [see Griffiths and Gray (1994), Griffiths and Knight (1997), Griffiths (2001)], cybernetic feedback [see Sarkar (1996a), Sarkar (1996b)], algorithmic complexity (Winnie 2000), evolved meaningfulness (Maynard Smith 2000a), evolved meaningful response (Jablonka 2002) and semioticity (Sarkar 2005).

Jablonka's (2002) work does the best in my opinion but is still limited by her development of an exclusively semantic approach. The failure of these accounts to capture what biologists mean is due to the fact that philosophical constraints hamper the ability of philosophers to explicate information talk. Specifically, the philosophical assumptions that an account of information be formal, decontextualized and monistic undermine our ability to figure out what biologists mean by information talk. The reason for these assumptions is that these are the philosophical requirements to justify the relevant distinction between genes and environments. They are philosophical conditions for the satisfactory determination of whether a given account philosophically justifies or undermines the informational distinction between the developmental roles of genes and environments. They have little to do with how and why biologists use information talk in their work. I argue that the way to move the debate forward is by abandoning these assumptions and looking to the details of scientific practice. Several of these assumptions come from the way the debate is framed around the question of whether only genes carry information. If we temporarily set this question aside and instead simply try to figure out what biologists mean by the information talk that they use, we will advance our understanding of information talk in biology.

The first assumption underlies what it is to be a satisfactory philosophical account; a philosophical account must be precise, preferably formal, and often reductive. Much of the debate explicates information talk in terms of the mathematically defined Shannon information or in a precisely articulated concept of semantic information. Both accounts reduce the imprecise information talk of biologists into the clearly set out concepts of reduction of uncertainty or evolved form. The reason that philosophers have focused on developing precise reductive accounts is that they are necessary for determining if only genes can carry information. If the account is imprecise, there is no way to determine whether or not it only applies to genes. It is not that there is anything wrong with precision or reductive accounts in general. The problem is that we should not assume that we need a precise, reductive account of information to understand what biologists mean when they use it. Precise, formal accounts are preferable, but they are not, as some philosophers would have you believe, the only accounts worth having.

The second assumption is the idea that the meaning of the concept of information must by itself pick out the relevant phenomena. Much of the debate consists in setting out different possible meanings of the concept of information and applying these information concepts to biological test cases. The assumption is that there is a simple, direct correspondence between the meaning of the concept of information and what it picks out in biological practice. This assumption is problematic because it blinds us to context dependent features of information talk due to differing styles of explanation. Differences in applications of information talk might be due to different contextual features of particular biological investigations. It is possible that biologists think that only genes carry information because of differences in the way the concept is used in different research traditions. Our explication of information talk should not assume that the key to understanding information talk is to set out a special meaning for the concept of information. It is certainly possible that biologists mean something ordinary by information and that differences in application can be explained by differences in relevant contextual features.

The final assumption is the denial of plurality. All of the relevant philosophical candidates seek to capture the meaning of biological information under a single account. The insistence that all usages of biological information should be made comprehensible by a single account blinds us to the diversity of informational applications in biology. It is entirely possible (and perhaps even likely) that biologists use informational concepts in different ways, with different meanings in different contexts. Insisting that a single account be capable of subsuming all of biological information is more likely to obscure than clarify what biologists mean. Embracing a pluralistic stance towards biological practice is a better approach (Kellert, Longino & Waters 2006).

The current debate represents the outcome of a particular style of philosophical reasoning that seeks to articulate a single, precise role for a concept whose meaning alone determines how it is applied. This program has challenged the philosophical justification of the claim that only genes carry information, shifting the burden of proof on to the philosophical defenders of this claim. The problem is that philosophers also seek to dismiss the role of information talk in biology. Often authors will end their argument that information does not play a particular role with the claim that as a result information talk is useless or misleading. This extension is a misstep. What they really mean is that, if you accept standard philosophical assumptions about what is scientifically relevant, then there is no role for information in biology; that is, all the arguments show is that to date we have not been able to articulate an account of information that meets our philosophical standards. Of course the key issue here is how appropriate are the philosophical assumptions which ground that judgment. I have argued that these assumptions should be abandoned if we are to understand the role information talk plays in biology. I propose an alternate strategy that puts capturing the meaning of the biologists first and worries about the justification of particular assertions like 'only genes carry information' second. The advantage of this approach is that our explication is not constrained by common philosophical assumptions. Additionally, if we can develop an accurate account of information talk, we are in a position to assess which philosophical assumptions are necessary to argue for particular claims. Working out from biological practice will illuminate our philosophical assumptions, instead of having our philosophical assumptions obscure the meaning of information talk in biological practice.

3. Signal

The primary focus of much of the philosophical debate on biological information is on the meaning of information itself. However, the significance of information in biology extends beyond the meaning of the concept of information alone and includes a wide range of related concepts like signal, code and network. These concepts are ubiquitous in biology and in the case of signal more prominent that that of information itself. Frequently, information is only mentioned in the introduction or conclusion of an article, while signaling dominates the bulk of the body of a great deal of papers. Elucidating the role that information talk plays in biological explanations requires an analysis of the whole family of related terms. For example, when biologists say something is encoded in DNA they describe an informational function without actually using the word 'information.' With the exception of Godfrey-Smith's work on the concept of code, (Godfrey-Smith 2000a, 2002) too little philosophical attention is focused on the relationship between terms like signal and network. Our aim should be to explore informational explanations including ones that do not use the term information. The term signal is especially important because of its striking prominence in current biological explanations.

Despite the extensive literature on information in biology, the concept of signal receives little philosophical attention. This is somewhat surprising because it is central to biological explanations in a way that the concept of information is not. New journals are exclusively dedicated to understanding signaling processes and their role in the functioning of complex biological systems. It is difficult to find descriptions of function and development that do not involve signaling processes in some way. Is talk of signaling merely colorful language unsupported by a coherent account as some philosophers argue is the case with information talk? Most, importantly what do biologists mean by signal?

4. Jablonka on Signal

One way to investigate what biologists mean by signal is to identify the biological processes they label as signaling. What phenomena are biologists picking out in the world and referring when they discuss signaling? Signaling processes involve molecules binding with cell surfaces leading to intracellular chemical cascades, which result in specific cellular activities like changes in cell metabolism or in the transcription of DNA. Although, there are clear exceptions to this generalized picture; three important features emerge. First, signaling processes involve molecules binding to cell surfaces. Second, signaling processes involve self-resetting, intracellular cascades as secondary messengers. Finally, signaling processes end with metabolic, structural or transcriptional changes in the cell.

Do these loose criteria define signaling processes by picking out all cases of signaling processes and only cases of signaling processes? Unfortunately, these features are neither necessary nor sufficient as criteria for signaling processes in biology. There are both exceptions to the general case and instances of processes which meet these features but are not signaling processes. As a result, we need to look beyond mere descriptive accounts of signal to get at what biologists mean.

Eva Jablonka offers an analysis of 'signal' as part of her account of biological information. Signals are special cases of biological information in which both the source and receiver are products of evolution. She says, "The term 'signal' will be reserved only for evolved informational inputs, that is, evolved inputs produced by an evolved or otherwise designed source" (Jablonka 2002, p. 582). The key idea in Jablonka's account of biological information is that there is information when there is an adaptive functional response to the form of a source. She reserves signal for cases in which there is an adaptive functional response to the form of a source and the source is the product of evolution as well. Since signal is a special case of biological information for Jablonka, it is necessary to set out her account of biological information to fully understand her account of signal. She describes information in the following way,

> …a source--an entity or a process--can be said to have information when a receiver system reacts to this source in a special way. The reaction of the receiver to a source has to be such that the reaction of the receiver can actually or potentially change the state of the receiver in a (usually) functional manner. Moreover, there must be a consistent relation between variations in the form of the source and the corresponding changes in the receiver." (Jablonka 2002, p. 582)

There are four key elements in her account of biological information. First, Jablonka conceptualizes information in terms of a source and a receiver. Variations in a source are read by a receiver. The source is an 'entity or process' which provides input. The receiver 'reads' the input and responds accordingly. Second, the receiver responds to the form of the source, in that it responds to the organization of the source, not its physical or chemical properties. Third, the receiver acts in a functional manner to the organization of the source. By functional, Jablonka stipulates that in cases of information the response is functional in both the ‘selected effects’(Wright 1973) and the ‘causal role’ (Cummins 1975) senses of function; that is, the presence of the response is explained by the fact that it is evolutionarily advantageous (Selected Effects sense) and the response contributes to the behavior of a containing system (Causal Role sense). Finally, there is a systematic relationship between variations in the source and variations in the response of the receiver. Variations in the organization of the source must reliably lead to variations in the adaptive functional responses of the receiver.

Jablonka argues that her functional criterion applies to two distinct concepts of ‘function,’ an evolutionary sense of function and a causal sense of function. The evolutionary sense is important because it provides the semantic foundation for the meaningfulness in her account of information. For Jablonka, signals are meaningful because they play a functional role in an evolutionary sense. In the evolutionary sense of function, the function of something explains its presence. For example, if you say that the function of the heart is to pump blood, according to a Selected Effects functional explanation the presence of heart is explained by its ability to pump blood. That is, you have a heart because your ancestors had such an organ that pumped blood. If you say that the function of a cellular signal is to play a particular role, you are explaining that the signal is there because it plays that role. A Wright functional explanation explains why the signal is present.

An alternative account of functional explanation is the causal account of function in which to explain the function of something is to describe its contribution to the maintenance of a capacity in a containing system. In this sense of functional explanation, the function of the heart is to play a particular kind of role in maintaining a capacity of the circulatory system. What is explained here is not the presence of the heart, but its contribution to a larger system.

For Jablonka, a something counts as a signal because it acquires meaningfulness because it form was shaped by evolution and this form is read in a functional manner where function is understood to include both evolutionary and causal senses of function. This analysis does not match the standard cell biology usage. First, cell biologists apply the concept of 'signal' to abiotic inputs that are not shaped by evolution. For example, heat shock proteins and other stress proteins involve environmental cues triggering cellular signaling processes, but molecular and cell biologists make no distinction between these signaling processes and those that involve evolved sources, but they should if Jablonka's account is right.

A second problem is that under Jablonka's account the source must respond to form of the input. Recall that by form Jablonka means that the receiver responds to the source's organization as distinct from its chemical and physical properties. The problem is that signaling molecules interact with various receptors by way of standard biochemical interactions. There is not a step in the signaling process in which the 'reading mechanisms' of the target cell are obviously responding to the form of the source. This is a problem for Jablonka's account because reacting to the form of a source is necessary for an interaction to be informational on the teleosemantic model. The receiver is supposed to react to the form as distinct from the chemical properties of the source. Of course, if every chemical interaction involves a reaction to form, Jablonka invalidates her original distinction between organization and physical/chemical properties.

Jablonka claims that something must have both kinds of functional roles to count as information. Her fusion of distinct modes of functional explanation obscures important differences and is mistaken. The problem is that biologists do not necessarily attribute a function in the evolutionary sense to signals. For example, Bishop, Buzko and Shokat (2001) outline experimental procedures for creating and manipulating signaling pathways. Radically new pathways are engineered to exhibit desired characteristics. These novel pathways clearly lack an evolutionary history and cannot have a function in the selected effect sense. The problem for Jablonka is that biologists still conceptualize them as signal pathways, which shows that a selected effects function is not necessary for a process to be considered a signal by cell biologists.

Ultimately, Jablonka's account of signal fails to capture the sense of signal typical of research in cellular biology. In the cell biology usage, signal does not set apart a special class of evolved inputs, nor involve a reaction to the form of an input nor necessarily play a role in Wright functional explanations. For Jablonka something is a signal if it is an evolved input read in a particular way. For cell biologists, something is a signal if a causal process plays a particular kind of functional role in a wider biological context.

5. Signal in Cell Biology

Once we relax the standard philosophical assumptions about what is required to philosophically account for biological practice, we can develop a relatively intuitive, straightforward understanding of how some biologists use signal. Signaling processes in cellular biology are best understood in terms of nested causal role functions. To be a signal is to have a distinctive kind of biological function. Many biological systems have mechanisms that allow for them to respond appropriately at one location in light of changes to the state of another part of the system. These are signaling mechanisms because of the functional role they play. Particular signaling mechanisms are also explained in terms of causal role function in which the capacity to signal is understood in terms of mechanisms that use the presence or absence of signaling molecules as proxies for states of a system at another location.

We can see why the schema outlined above is not enough to provide an account of signal. It lacks the broader functional context that makes a signal a signal. Consider a biological capacity like quorum sensing in bacteria. Some bacteria have the capacity to act in a coordinated fashion. They regulate their behavior depending on colony density. For example, the bacteria V. fischeri live in a symbiotic relationship with the Hawaiian Bobtailed squid—producing bioluminescent compounds when densely packed in the squid's light organ. Quorum sensing bacteria produce signal molecules known as autoinducers and also have an autoinducer binding site. In normal environments, it is rare for a bacterium's own autoinducer to bind with its own binding site. In colonies, the concentration of autoinducers increases in an environment. Some of the available autoinducer binds with the bacteria's autoinducer receptors triggering still more production. When the threshold is reached and the receptor is fully activated, the receptor triggers a change in DNA transcription producing the bioluminescent compound. Many things play a causal role function contributing to this capacity. Quorum sensing counts as a signaling process because it allows for communities of bacteria to act appropriately given the state of the system at a different location. The capacity of quorum sensing is explained in terms of a mechanism that uses the presence or absence of autoinducer as a proxy for community density.

5. Conclusion

A quick look at the concept of biological information from the perspective of practice reveals that signal is the most noteworthy informational concept in biology. If we look at signal unencumbered by standard philosophical assumptions, we can make sense of the work signal does in specific biological explanations. It describes a particular kind of biological function, one in which a system uses one thing to act as a proxy for another. I argue that we can learn more about biological practices if we do not insist that our philosophical accounts must be precise, decontextualized and monistic. We can consider the justification of biological concepts once we have a clear picture of the work done by them. If the above analysis of signal is correct, questions about the philosophical significance of biological information are really questions about the philosophical significance of functional explanation in biology and need to examined in that light.

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