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BEING EMERGENCE VS. PATTERN EMERGENCE

Complexity, control and goal-directedness in biological systems

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1. Introduction

Emergence is much discussed by both philosophers and scientists. But, as noted by Mitchell (2012), there is a significant gulf; philosophers and scientists talk past each other. We contend that this is because philosophers and scientists typically mean different things by *emergence*, leading us to distinguish *being emergence* and *pattern emergence*. While related to distinctions offered by others between, for example, strong/weak emergence or epistemic/ontological emergence (Clayton, 2004, pp. 9–11), we argue that the being vs. pattern distinction better captures what the two groups are addressing. In identifying pattern emergence as the central concern of scientists, however, we do not mean that pattern emergence is of no interest to philosophers. Rather, we argue that philosophers should attend to, and even contribute to, discussions of pattern emergence. But it is important that this discussion be distinguished, not conflated, with discussions of being emergence. In the following section we explicate the notion of being emergence and show how it has been the focus of many philosophical discussions, historical and contemporary. In section 3 we turn to pattern emergence, briefly presenting a few of the ways it figures in the discussions of scientists (and philosophers of science who contribute to these discussions in science). Finally, in sections 4 and 5, we consider the relevance of pattern emergence to several central topics in philosophy of biology: the emergence of complexity, of control, and of goal-directedness in biological systems.

2. Being emergence

Being is a very old subject in philosophy and has been at the center of the branch of philosophy known as metaphysics. Roughly, the more *real* something is, the more *being* it has. Physical objects are thought to be *real* to a degree that imaginary objects are not. Philosophers disagree about whether it makes sense to talk about things being *more* real or *less* real than others, but such debates are nowadays usually carried out not directly in terms of "being" but in terms of *ontology*. An *ontological scheme* defines what types of entities there are (i.e., what *ontological categories* entities can fall into) and how they are related. Instead of talking about entities of one ontological category being "more real" than another, it is now more common for philosophers to say that one ontological category is "more fundamental" or "grounded by" the other, or that the one ontologically "reduces to" the other. However, this represents more of a superficial shift in word choice than a substantial shift in topic.

The idea of levels of being, with the denizens of some levels of being dependent on those at lower levels, is traceable at least to Aristotle, who argued that metaphysics, as the inquiry into being qua being, provided the most fundamental knowledge:

> [H]e who knows best about each genus must be able to state the most certain principles of his subject, so that he whose subject is being qua being must be able to state the most certain principles of all things. This is the philosopher.
>
> *(Metaphysics, 1005b9–11)*

Fundamental to inquiry for Aristotle was determining the true categories of being, with *primary substance* – "that which is neither said of a subject nor in a subject" (*Categories*, 2a14) – providing the foundation because "if the primary substances did not exist it would be impossible for any of the other things to exist" (ibid, 2b6).

Despite his departures from Aristotle and the scholastic tradition on many topics, Descartes also defended the idea of levels of being – "there are various degrees of reality or being: a substance has more reality than an accident or a mode" (CSM 2, p. 117). For Descartes, a single category of being was fundamental: God. Subordinate to God were the categories of mind (thinking substance) and body (corporeal substance). These latter two were "really distinct," that is, ontologically independent: "two substances are said to be really distinct when each of them can exist apart from the other" (CSM 2, p. 114). When characterizing knowledge, Descartes emphasized the importance of knowing what is foundational. He thus gave voice to two ideas that have played an important role in subsequent philosophy: 1) that in order to have true knowledge, we must know what is fundamental in terms of being and 2) what is prior in terms of being cannot come from (i.e., cannot *emerge* from) what is posterior in terms of being.

When Descartes addressed knowledge of the physical world, he defended a mechanistic perspective which derived explanations of compound objects from the properties of their corpuscles. This emphasis on constitution was also developed by Locke, who traced the essence of a thing ("the very being of anything, whereby it is what it is", *An Essay Concerning Human Understanding*, III.iii.15) to its constitution, "which is the foundation of all those properties that are combined in, and are constantly found to co-exist with the nominal essence; that particular constitution which everything has within itself, without any relation to anything without it" (III.iv.6). While acknowledging that we do not know "the internal constitution, whereon their properties depend . . . that texture of parts . . . that makes lead and antimony fusible, wood and stones not" (III.iv.9), he nonetheless assigned them priority both in terms of being and knowledge.

The tradition of Descartes and Locke continues in those contemporaries, exemplified by Kim, who treat the properties at the lowest level of composition as the foundation of the being of all compound entities that provides the explanation for all compound entities. Those who oppose being dependence and being reduction then argue for some version of being emergence.

We can chart these positions by defining the being and being-dependence of any entity:

The **being of X** $=_{\text{def}}$: If the ontological category of X is C, then the *being of* X is whatever it is about X that allows it to count as an instance of C.

Y is **being-dependent on X** $=_{\text{def}}$: Y's counting as an instance of ontological category C_1 is dependent on X's counting as an instance of ontological category C_2 (for some C_1 and C_2).

With these definitions on the table, we can make more precise the conceptions of reduction and emergence that Kim and many others employ. First, ontological category X *reduces to* ontological category Y if the being of X is *all there is* to the being of Y. An example will clarify. Suppose one type of particle, called an *X particle*, is made up of smaller particles, known as *Y particles*. Something counts as a Y particle if it meets the criteria for a Y particle; in other words, if certain facts obtain. This is also true of an X particle: something only counts as an X particle if the criteria for X particles are met. Now suppose you have a collection of Y particles that form an X particle. If the *facts* that allow the collection of Y particles to count as an X particle are nothing over and above the *facts* that allow the collection of Y particles to count as a collection of Y particles, then X particles *reduce to* Y particles. But if the obtaining of the latter set of facts is only dependent on, not identical to, the obtaining of the former set of facts, then Y is *being-dependent on* X but not reducible to X. Reduction in this sense (we will use the term "being-reduction") entails being-dependence, but being-dependence does not entail being-reduction.

If X is being-dependent on Y but X does not reduce to Y, then X *emerges from* Y. Like reduction, emergence is a relation with two relata: the *emergence base*, from which something is said to emerge, and the *emergent*, that which has emerged. If X particles were emergent in this sense (i.e., *being-emergent*) from Y particles, this would mean that there would be more to the facts that allow the collection of Y particles to count as an X particle than merely the facts that allow the collection of Y particles to count as a collection of Y particles.

Philosophers have used a variety of other terms for being-dependence: ontological dependence, ontological ground, substrate, ontological priority, realization, constitution, truth-maker, componency, noncausal determination, compositional relation, etc. All of these capture the idea that the being of higher-level entities is dependent on those at a lower level. Issues about being-dependence are sometimes raised in terms of "determination," "explanation," or the ability to completely "account for" one ontological category in terms of others. For example, are higher-level entities something more than the components that constitute them or "completely determined by" their constituents? Is a chemical element, such as carbon, completely "accounted for" in terms of the protons, neutrons, and electrons that constitute it? Or are mental states completely "accounted for" in terms of the neurons and other cells that constitute a person's brain? Discussions of *downward causation* are usually centered around being emergence: Do whole entities (e.g., living cells) have properties "over and above" those supplied by their components (genes, proteins, etc.) such that they can have causal effects "independent of" the effects of their constituents? This issue has acquired urgency in the wake of Kim's (e.g., 1999) arguments to the effect that all causation can be "adequately accounted" at the most basic level – assuming that the most basic level is closed so that all effects are determined by causal processes between the occupants at that level – and any causation attributed to wholes built from these constituents is "redundant." Thus, there is nothing to be "explained" in terms of the activities of the wholes. The only way, in Kim's analysis, for minds to exhibit independent causal effects is if dualism is true and minds are neither reducible to nor being-dependent on physical things.

3. Pattern emergence

Having clarified the notion of being emergence, we set it aside. When scientists take up the concepts of emergence and reduction, they are typically not concerned with being and whether the being of one entity can be completely accounted for in terms of its constituents. In part this is due to the focus of scientists on ontology-neutral explanation – on accounting for the phenomena they encounter without taking a metaphysical stance on the underlying ontology. Unlike contemporary philosophers, scientists have to a large extent moved on from the Ancient Greek notion that pursuit of knowledge requires the pursuit for more fundamental levels of being.

Bogen and Woodward (1988) characterize phenomena as repeatable occurrences in the world involving particular types of entities. Although the ontological status of the entities involved may be important for some purposes, phenomena also depend critically on how the entities are *organized*. The same organization can occur among entities regardless of their ontological status. Accordingly, in studying organization, researchers can and often do abstract from considerations about which things are "more real" and focus on patterns exhibited in the phenomena. Explaining a pattern requires an account of how it was generated. Researchers come to treat some patterns as emergent when one cannot account for their generation in the same manner as patterns regarded as more basic. Since patterns are abstract and can be analyzed in disregard of the ontological status of their elements, discussions of pattern emergence are not focused on being.

Studying patterns and their emergence has become important for a wide range of fields over the last several decades. Condensed matter physics deals with "emergent" critical phenomena such as superconductivity, superfluidity, and ferromagnetism. Prigogine pioneered the concept of dissipative structures to understand the emergence of systems that maintain stability far from equilibrium. Chaos theory was developed to understand systems that generate complex and unpredictable, yet determinate, behavior from simple dynamical rules. Mandelbrot developed fractal geometry to understand the emergence of self-similar patterns in nature. Catastrophe theory was developed to understand systems that generate significant or complex effects from simple or minor perturbations; catastrophe theory is part of the more general field of nonlinear systems and complexity theory that examines the mathematics of a wide range of emergent phenomena. Neural network theory deals with systems capable of exhibiting intelligent or adaptive behavior based on nodes that interact in simple ways. Developmental biology is concerned with emergent processes in morphogenesis and tries to understand how from natural selection and environmental constraints complex biological structures and functions can develop. The field of genetic algorithms draws from concepts like evolution and natural selection to develop algorithms that are employed in information processing applications such as optimization and search.

What the areas listed here (sometimes labeled collectively as the "complexity sciences"; Stein, 1989) have in common is that particular patterns *emerge* as entities are configured in particular ways. The emergence of patterns can be addressed independently of questions about ontological fundamentality, or about what is "more real" than what is not. We can recognize the concern with pattern even in some of the statements of philosophers whose primary focus is on being. Sider states:

> Consider questions of ontology, for example. There has been much discussion recently of whether tables and chairs and other composite material objects exist. It is generally common ground in these discussions that there exist subatomic particles that are "arranged tablewise" and "arranged chairwise"; the controversy is over whether there exist in addition tables and chairs that are composed of the particles.
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> *(2011, p. 7)*

The concern with pattern is captured in the reference to a tablewise *arrangement* of particles. Moreover, we can establish whether or not there is such a pattern independently of addressing questions about whether a level of reality is fundamental and whether any particular arrangement of fundamental stuff will count as an entity. A tablewise arrangement is an example of a pattern, albeit perhaps not a particularly interesting one. Moreover, it is not itself an ontological category; rather, patterns are *candidates* for ontological categories depending on what instantiates them.

Patterns are a central concern for scientists, who investigate how they come about from simpler patterns, what are their properties, etc. Conway's Game of Life (Berlekamp, Conway, & Guy, 2004, chapter 25) illustrates these questions. The Game of Life is laid out on a grid of squares, and simple rules that take into account the state of neighboring squares at a previous instance determine whether a given square is on or off. Given some initial arrangements of on-squares, enduring patterns such as gliders emerge that move as a unit across the grid. Gliders exist, and their emergence and behavior are objects of investigations without raising questions of what type of being they enjoy. Given the gap between the rules that govern squares in the Game of Life and the behavior of gliders, some might view gliders as emergent patterns.

4. Some approaches to characterizing pattern emergence

There are parallels between discussions of being emergence and pattern emergence. With pattern emergence, there is again an emergence base and an emergent: the emergent pattern is in some way dependent on the emergence base pattern. The emergent pattern is also, in some sense, something more than the emergence base pattern. The sense in which the emergent pattern is "something more" differs between contexts, but recently some authors have explored whether there is more to say about what the interesting cases of pattern emergence from the various fields listed earlier have in common, and have taken important steps towards understanding general principles of pattern emergence. With pattern emergence, as with being emergence, the criteria can be ontic, epistemic, semantic, etc. But it is important to keep the criterial dimension (sometimes also referred to as the "weak/strong" dimension) separate from the being/pattern dimension.[1] In the following subsections we review the proposals of several theorists who aspire to develop a general theory of pattern emergence that would enable insights about how patterns that emerge in one field (e.g., theoretical biology) can be applied to pattern emergence in another (e.g., computer science).

4.1. *Pattern emergence as bifurcation*

Hooker analyzes pattern emergence from the standpoint of dynamical systems theory (DST), a powerful framework for understanding how any kind of system (whether discrete or continuous) changes over time. Central to DST is the concept of a *state space*, "an abstract mathematical space of points where each point is assumed to represent a possible state of the target system" (Bishop, 2012, p. 4). One can then represent the history of the system as a trajectory from an initial state to a final state and employ mathematical tools to analyze the trajectory. What makes DST appropriate is that 1) pattern emergence is usually considered to be something that occurs (or can be modeled as occurring) over time; 2) DST, like the notion of a "pattern," can be applied to any system of elements (as long as they can be described in terms of a state space), regardless of their intrinsic nature; and 3) DST models characterize change in a system using mathematical equations, which assumes that in some sense information about how the system changes over time is compressible (i.e., that it is organized into patterns).

In Hooker's view, we can look at pattern formation as a spectrum running from trivial cases such as the assembly of legs and a top into a table to the emergence of patterns through highly complex processes like biological evolution and creative intelligence. The challenge is to specify when it is useful to appeal to emergence. Hooker rejects epistemic criteria for emergent patterns as problematically subjective, and instead argues in favor of conceptualizing pattern emergence in terms of what is referred to as bifurcation in dynamics, "for then a new behavioural pattern develops, and one whose occurrence is dynamically grounded in a shift in dynamical form"

(2011, p. 209). What Hooker means by a "shift in dynamical form" is that "a differently structured dynamical equation is required to model the behaviours and the pattern of all possible trajectories (the flow) changes" (2013, p. 759). The appeal to equations does not, however, imply that Hooker is invoking a semantic, epistemic, or otherwise mind-dependent criterion. New equations are required as a result of the introduction of constraints, which are objective features of the system itself.

The idea of constraints stems from classical dynamics. Newton's laws fully characterize the behavior of any particle, but they specify each particle's behavior in terms of six variables for the six degrees of freedom it enjoys. Macro-scale objects result from constraints that restrict the degrees of freedom. For example, when two particles are bound together, the particles are constrained to move together. When water molecules are constrained by a pipe, they are restricted to moving in the direction of the pipe. In some cases, one can incorporate the constraints into the equations describing the particles' behavior, but in other cases, one cannot. One cannot, for example, derive the equations Maxwell developed for governors (feedback systems) from basic Newtonian equations.

4.2. Pattern emergence as nonlinearity or instability

Hooker's appeal to "differently structured" dynamical equations leaves open a variety of ways to specify the difference other than bifurcations. Bishop (2012), for example, similarly appeals to the DST framework to account for emergence, but appeals to the distinction between linear and nonlinear dynamical equations. A linear equation exhibits superposition: the output of an operation on a variable α is proportional to α. When superposition fails, the equation is nonlinear. In the context of a physical system described by such equations, Bishop states:

> this failure corresponds to a system's output *not* changing proportionally to any change in input. The phenomenon of *sensitive dependence* – the smallest change in the initial conditions can issue forth in a drastic change in a system's behaviour – registers this non-proportional response.
>
> *(2012, p. 4)*

One reason nonlinearity is an interesting point of demarcation is that one can decompose systems described by linear equations into their parts, analyze each independently, and then sum together the results. As Bishop comments, "Reductionist lore tends to work well for such systems." But reductionist strategies are insufficient with nonlinear systems since they respond differently to different inputs given the constraints, which determine the whole. Nonlinear systems often exhibit self-organizing properties: "The interplay between parts and wholes in complex systems and their environments typically leads to the self-organization observed in such systems" (2012, p. 6).[2]

Most traditional scientific analyses have focused on systems that maintain stability under perturbations. Some nonlinear systems, such as two-dimensional planetary systems, are stable, but many are not. Schmidt (2011) argues that nonlinear systems that exhibit instability should be counted as emergent. Stability and instability, though, come in various forms. Schmidt characterizes three kinds of stability that, when violated, give rise to emergence: static, dynamic, and structural. Static instability results from sensitivity to initial conditions at a single point or region of a state space, where "the alternative trajectories from two nearby initial points separate and will never again become neighbors" (2011, p. 228). Dynamic instability begins less localized: "nearly all points in the state space exhibit the property of sensitivity: the trajectories separate exponentially by time evolution" (2011, p. 229). In other words, a dynamical instability is exhibited when the system as a whole is chaotic. A Lorenz system is an example of this: almost all initial conditions lead to chaotic solutions. Finally, Schmidt defines *structural instability* as a kind of higher-order instability: if one were to perturb the structure of a system (i.e., its equations or laws) slightly, then "the overall dynamics changes qualitatively" (2011, p. 230).

4.3. Complementarity

Pattee agrees that dynamical conditions such as bifurcation, nonlinearity, and instability provide for important types of pattern emergence, but contends they do not capture the form of pattern emergence found in living systems. These dynamical conditions exhibit rate-dependent phenomena. But he argued that biology also generates rate-*independent* phenomena. The switching of a light switch provides a simple example of a rate-independent phenomenon. Flipping the switch requires the application of a certain threshold level of energy to the switch, but once it is flipped, the light is turned on or off independently of the energy applied to the switch. Dynamical information about the speed with which it is flipped is filtered out by the system and is irrelevant to the resulting behavior. Only a binary signal is sent to the light from the switch, with no information about the rate at which the switch was flipped. (See Rosen, 1969, for a similar development of the complementarity of multiple descriptions.)

Pattee argued that rate-independence is common in biological systems. For example, molecules act as signals, that is, the molecules consistently have a specific effect, regardless of when they are received by a consumer. Rate-independence is important for many kinds of biological processes: examples include sensor transduction, gene transcription and translation, error correction, enzymatic recognition, any type of memory, and any type of regulation or control. A general theory of pattern emergence needs to be able to account for the emergence of these types of organization.

Pattee (1987) argued that rate-independence can give rise to the emergence of *informational constraints*, in which the information carried by a state, not its dynamics, constrains behavior. Information constraints are distinct from but complementary to dynamical nonlinearity/instability:

> Although it is true that dynamical theory and symbolic information are not associated in our normal way of thinking, they are epistemologically complementary concepts that are nevertheless both essential for a general theory of biological self-organization. Moreover, instabilities are the most favorable condition of a dynamical physical system for the origin of nondynamical informational constraints, and the evolution of self-organizing strategies at all levels of biology require the complementary interplay of dynamical (rate-dependent) regimes with instabilities and nondynamic (rate-independent, nonintegrable) informational constraints.
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> *(1987, p. 198)*

Although they complement one another, Pattee contended that one cannot describe or model rate-dependent dynamical and rate-independent informational constraints in the same vocabulary. The vocabulary that describes a switch as "closing" or "opening" is different from the vocabulary that refers to the velocity with which the switch was moved. He characterized the complementarity as *semantic closure*, a type of closure in which rate-dependent constraints are dependent on rate-independent constraints, and vice versa, within the same system. The switch must be moved with some velocity in order to close it. Engineering regularly takes advantage of the complementarity of different descriptions of a system. To analyze an electrical circuit involving switches, one ignores rate-dependent features and treats them as rate-independent. Rate-independence is even more fundamental in biology.

5. Pattern emergence applications

Two emergent features of living systems that are challenging to explain are hierarchical control and goal-directedness. We briefly consider how Pattee's framework of treating rate-dependent and rate-independent features as complementary provides a way of understanding these forms of pattern emergence.

5.1. Control

When a system is considered purely in terms of dynamical physical laws, there is no possibility of control. Every detail of what happens is determined by the laws, and no freedom is left open to a controller to make use of:

> [T]he forces that enter the equations of motion determine the change in time of the state of the system as closely as determinism is allowed by physical theory. The whole concept of physical theory is based on the belief that the motions or states of matter are neither free nor chaotic, but governed by universal laws.
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> *(1973, p. 85)*

If there is no freedom to move in different ways, there seems to be no role for control. Pattee's solution at first seems counterintuitive: the possibility of control only arises though "some selective loss of detail" (1973, p. 80).

The challenge, then, is to explain how "'selective loss of detail' can lead to hierarchical control instead of the usual loss of order in the system" (Pattee, 1973, p. 81). This results from describing the system in a way that leaves out detail. This is what we do when we speak of the degrees of freedom available to a particle. Only in that context can we identify constraints that limit those degrees of freedom. In abstracting from detail, we abandon the lowest level, where everything is determined, and adopt what Pattee speaks of as a higher level of description:

> [T]he physicist's idea of constraint is not a microscopic concept. The forces of constraint to a physicist are unavoidably associated with a new hierarchical level of *description*. Whenever a physicist adds an equation of constraint to the equations of motion, he is really writing in two languages at the same time. The equation of motion language relates the detailed trajectory or state of the system to dynamical time, whereas the constraint language is not about the same type of system at all, but another situation in which *dynamical detail has been purposely ignored*, and in which the equation of motion language would be useless. . . . A constraint requires an *alternative description*.
>
> *(1973, pp. 85–86)*

Why would a scientist ever opt for less detail than is possible? One reason is to characterize macroscopic objects. Macroscopic objects, whether tables or organisms, are not identified in the lower-level dynamical account. They are patterns that can only be identified by recognizing freedom of motion and how this freedom is constrained. They arise in a higher-level language.

Talk of abstraction and languages is usually associated with cognitive activity of observing minds. The talk of constraints and control, however, is intended to refer to something that can operate independently of any mind. The relevant abstracting and imposing of constraints is not done by the scientist, but occurs in the very systems being described. This requires things in that system that can classify "microscopic degrees of freedom of the lower level it controls" (Pattee, 1973, p. 89) – that is, treat different conditions specified at the lower level as the same – and then apply the same rule to all instances. Exercising control, Pattee argues, requires that the system 1) classify situations (Pattee's general term for this is "measurement"), 2) make a *record* (or representation) of what was classified, and 3) respond differentially in light of the record (i.e., the record must be "*read out* inside the system," 1970, p. 132). These together generate what Pattee in the passage earlier from 1987 referred to as *informational constraints*. Together, Pattee refers to this as a *classification-record-control* process (1970, p. 132).

Pattee argues that these conditions are met even in enzymes. An enzyme classifies substrate molecules, changes its conformation when it binds to one with the right shape, and then catalyzes a reaction. The enzyme thereby controls the reaction. The importance of this is even clearer with allosteric enzymes. By binding with one molecule that results from a different reaction, such an enzyme changes how it catalyzes a given reaction. It is thereby sensitive to information about other conditions in the cell than the presence of its substrate. Such an arrangement is also present in the interaction of a neuron with a muscle: the muscle contracts when it recognizes an incoming neurotransmitter, represents this information in a calcium store, and uses that representation to release actin and myosin to slide along each other. In such systems, we can talk about control as existing in an observer-independent, intrinsic way within the system, because the system itself (and its capacity for classifying, recording, and interpreting its own records) defines the necessary complementary mode of description.

5.2. Goal-directedness

The resources required to account for control also provide a basis for explaining the goal-directedness of biological systems, which has long been a point of contention between reductionists and emergentists. In part the controversy reflects ambiguity in what is meant by "goal-directedness." McFarland (1989) usefully distinguishes three senses: goal-achieving, goal-seeking, and goal-directed systems. A goal-achieving system is "one which can recognize the goal once it is arrived at (or at least change its behaviour when it reaches the goal), but the process of arriving at the goal is largely determined by the environmental circumstances" (1989, p. 108). Such a system performs what Pattee calls "measurement," but also progresses towards the goal *by means of* such measurements. A goal-seeking system progresses towards the goal as a result of its own organization or design. In doing so it may rely on what are sometimes called passive control systems (Milsum, 1966) that measure or represent information. Accordingly, neither goal-achieving nor goal-seeking systems exhibit control in the sense Pattee characterized. They pose no challenge for the reductionist, as they do not exhibit interesting pattern emergence.

Interesting pattern emergence arises with what McFarland defines as goal-directed systems since they both represent a goal and produce behavior in response to that representation:

> In the paradigm case of goal-directed behaviour, the difference between the "desired" state of affairs and the actual state of affairs (as monitored in the negative feedback pathway) provides the (error) signal that actuates the behaviour-control mechanism.
>
> *(McFarland, 1989, p. 108)*

What McFarland describes here is a form of negative feedback control: the system that measures some variable, compares it to a set-point value, and based on the comparison responds one way rather than another. This differs from the cases noted earlier in that it is a goal, not a state of the system or the environment, that is represented.

What does it mean for a goal to be explicitly represented in a system such that its behavior is governed by that representation? Dennett offers an ecumenical conception of explicit representation:

> Let us say that information is represented *explicitly* in a system if and only if there actually exists in the functionally relevant place in the system a physically structured object, a *formula* or *string* or *tokening* of some members of a system (or "language") of elements for which there is a semantics or interpretation, and a provision (a mechanism of some sort) for reading or parsing the formula. This definition of explicit representation is exigent, but still leaves room for a wide variety of representation systems. They need not be linear, sequential, sentence-like systems, but might, for instance, be "mapreading systems" or "diagram interpreters."
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> *(1987, p. 216)*

What is crucial in this account of goal-directedness is the addition to Pattee's account of control the intermediate step of directly comparing measurements of a system or environmental variable with an internal "goal" state variable. Any system that selects behaviors based on such a comparison is a goal-directed system. Such goal-directed behavior is widespread in biology. It is exhibited, for example, in bacteria that "decide" whether or not to sporulate depending on certain variables, such as the concentration of intracellular GTP (guanosine triphosphate) falling in a specified range (Stephens, 1998).

Goal-directedness is a form of pattern emergence that provides for novel forms of behavior in organisms that exhibit it. The goal-directedness of bacteria may seem far removed from the goal-directedness of humans, but what Pattee argues is required in relatively simple biological systems – representations of goals – can be extended by extending the representational machinery. Rosen (1985), for example, explored how representations of anticipated future states of a system and its environment can be used to control the system in the present. More advanced forms of information processing, such as representing alternative futures and selecting between them, require additional representational machinery. The result is the emergence of different patterns of behavior, but the key, in Pattee's analysis, is semantic closure that links the rate-independent informational constraints provided by a representation system to the fully determinate, rate-dependent, dynamical behavior at the lowest level.

6. Conclusions

In the past, scientists and philosophers have run into dead ends by conflating the emergence of phenomena like complexity, control, and goal-directedness with questions about the emergence of being. Increasingly philosophers and scientists who address the emergence of patterns independently of the emergence of being are advancing interesting and useful accounts about when patterns emerge. We have sketched a few of these and then focused on one framework, attributed to Pattee, that offers potential for understanding the emergence of hierarchical control and goal-directedness in biology.

Notes

1 Humphreys (2016, p. 150) uses "pattern emergence" in a different sense from the one used here. In our terminology, Humphreys is referring to a certain type of semantic criterion for being emergence. Humphreys subsumes "pattern emergence" under the larger category of "inferential emergence." Something

like what we are calling "pattern emergence" is also briefly suggested by Clayton (2004, p. 17), but Clayton does not treat this as separate from other distinctions about emergence.

[2] Linearity is one of four conditions Wimsatt (2007, pp. 280–281) offers for a system counting as aggregative. The others are intersubstitution of parts, size scaling, and decomposition/reaggregation. When aggregativity fails, Wimsatt counts the behavior of the system as emergent.

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