The Musical Organism

Metaphors and Metaphysics of Biology

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Abstract

Is it useful to think about organisms in terms of music? This thesis navigates a strange territory, where the lands of biology, music, metaphors and metaphysics meet. A recent and popular idea among theoretically-minded biologists is that development is best understood as a musical performance: an open-ended creative act, involving interpretation and improvisation. I argue that this metaphor of musical performance can be a theoretically fruitful one, and that it presents an interesting alternative to dominant 'machine metaphors', like 'genetic program.' My argument begins with an explication of conceptual metaphor theory and the various functions of metaphors in science. I next identify a clash of metaphor, between machine and music, between genetic program and developmental performance. Musical metaphors in the literature aim to voice ideas about development and evolution that move beyond the gene; ideas from systems biology, evo-devo, and developmental systems theory. Though apparently used for rhetorical purposes, I argue that machine- and musical metaphors make two very different ontological commitments, and that this is key to the musical metaphor's heuristic and theoretical potential. Namely, it relies on a different ontology of life: while the animal machine is a thing with parts, a hierarchy of substances, the musical organism is a process with relatively stable patterns of interaction. I argue that biology is better served by a processual ontology, and that a musical conception of organisms that relies on this premise can open up ways of thinking about life that the deterministic, mechanistic picture does not capture.

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Contents

1 Introduction

"Molecular biology could read notes in the score, but it couldn't hear the music," so Carl Woese in 2004 commented on the state of biology at the end of the twentieth century (Woese, 2004, 175). Woese presumably meant that a musical score does not entirely determine a particular performance of that score, and that similarly the nucleotide sequence of the DNA alone does not entirely determine how a multicellular individual grows, changes and takes the forms and functions that it does. [1]

Woese is neither the first nor the only one to use such a musical metaphor to comment on the phenomena of life. The musical arts have been a sustained source of inspiration for many biologists, especially those who, following Kant, marveled at the self-organization that characterizes organisms. Karl Ernst von Baer (1792-1876) wrote: "I believe it is possible to compare the various Life-processes to musical thoughts or themes, and call them creative thoughts, which build their own bodies themselves" (1864, 281 [my translation]). Jacob von Uexküll (1864-1944) conceived of the reciprocal causal relationship between parts and wholes, between individuals and environments, as counterpoint voices singing a duet (Amrine, 2015, 52-53). And Alexander Oparin (1894-1980) characterized organisms as musical works, "such as a symphony, the actual existence of which depends on determinate sequences and concordances of individual sounds. One has only to disturb the sequence and the symphony as such will be destroyed, only disharmony and chaos will remain" (Bedau and Cleland, 2010, 79).

More recently, music has again surfaced. This time specifically in discussions over the relationship between that most elusive of molecules in the cell, and the forms and behaviors of living beings that are made up of those cells: "The genome sequence is a Jazz score" (Porta, 2003, 29), life is a symphony without a conductor (Noble, 2006,

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[1] Woese may not have known of Gene Music, or probably he simply did not mean 'music' in that sense. Namely, there exists a lively community of molecular biologists from around the world who create 'music' from nucleotide and polypeptide sequences. Nobuo Munakata writes: "Genes and music are two heritable systems that underlie our life. Both of them are linear and quantized information. I try to explore the correspondence and metaphor between them by converting gene (DNA, RNA, and protein) sequences to MIDI sequences. Hopefully, gene music can capture and inspire appreciation of the diversity, mystery, and beauty of life" [taken from Munakata's *Gene Music and Sangen Studio*'s webpage]. From the present paper it should become clear that this static, deterministic understanding of the relationship between score and music is faulty, and indeed not desirable when relating music to organisms.
The world of Gene Music is fascinating nonetheless. For more, see: the 'Gene2Music' project at UCLA; Dunn and Clark, 1999; and the YouTube-playlist 'Gene Music Video' by 'nomunak.'

113) and development is an ongoing performance of a musical piece, which requires both interpretation of- and improvisation on the score (Gilbert and Bard, 2014). What are we to make of this music-talk?

That metaphors matter in science has become widely recognized and emphasized.[2] "Science cannot be conducted without metaphors" (Lewontin, 1996) is a popular quote, just as is Norbert Wiener and Arthur Rosenblueth's saying that "the price of metaphor is eternal vigilance" (Ibid., 1). The latter points to the Janus-faced nature of metaphors: we need them, but they bite. Metaphors are powerful parts of research and theory, but they have their limitations, as they shed but a partial light on what they help to capture. Metaphors that come to be taken as the whole story become obstacles rather than tools.

Metaphors of biology's "century of the gene" (Keller, 2000) have received, and still do receive particular attention. And criticism. Under the umbrella of the so-called 'machine metaphor' a host of terminology, explanatory frameworks and research strategies have been introduced and sustained in the various disciplines of biology: genetic control, -program, -code, molecular machines, feedback, reverse engineering, too many to list. Indeed, the machine metaphor is often thought of as "perhaps the most powerful conceptual tool of modern biology" (Konopka, 2002, 398). But also one that many think has come to dominate biological thinking, obstructing progress. In many ways, biologists have been moving away from the rigid image of living machines to a more dynamic and fluid one: "the challenge is to design an exciting plot about complexity in the absence of hierarchically ordered pairs of opposites" (Van der Weele, 2004); opposites such as for example nature/nurture, individual/environment, self/other, genotype/phenotype. And this move implicates a change in metaphors.

One class of metaphor that has come to the fore are metaphors of *musical performance*, such as the ones above. They surface in discussions concerned with evo-devo, the Extend Synthesis, systems biology, and Developmental Systems Theory. Here, score, performance, improvisation and playing together feature as alternatives to program, control, regulation and competition.

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[2] A number of classical sources include Hesse, 1966; Ortony, 1993; Radman, 1995. Concerned more specifically with the life sciences are Haraway, 1976; Keller, 1985, 2002; Van der Weele, 1999; Oyama 2000; Draaisma, 2000; Brown, 2004.

In this paper, I look specifically at those recent metaphors of musical performance, and compare them to the machine metaphors they are meant to confront. There is an increasing amount of research on the ways in which metaphors function in science. My first objective will be to see in which way these musical metaphors are both presented as an alternative and used. Namely, are they more than mere rhetorical devices that can combat faulty public images of genetic determinism, and indeed as heuristic or theory-constitutive concepts? Secondly, I ask what is different between musical and machine metaphors. I argue that the crucial difference between them is the ontology of living beings which they assume: the living machine is a thing with parts, a hierarchy of substances, while the music of life is a process with relatively stable nodes of interaction. This is an important difference, as it opens up to ways of thinking about life that the deterministic, mechanistic picture does not capture. Something that many take to be sorely needed: "there are powerful reasons for thinking that emancipation from the mechanistic paradigm is a precondition for true insight into the nature of biological processes" (Dupré, 2008, 31).

The paper is structured as follows. In part 2 I trace a lineage of thinking about what metaphors are and how they are involved in science. Once metaphorical reasoning is understood as an integral part of human conceptual sense-making in general, we can expect that scientific contexts make no exception; metaphors are not only tools of rhetoric, but are part and parcel of the development of scientific research and ideas. In part 3, I show how musical metaphors have repeatedly been proposed as alternatives to the notion of a genetic program. For the most part, they are used to *illustrate* the complexity of causation in living systems and the indeterminacy of ontogeny, thus functioning as *rhetorical* metaphors. Part 4 then suggests that the musical metaphor can nonetheless present a theoretically interesting alternative to machine metaphors, as it understands the organism as a *process* rather than a *thing*, and accordingly highlights aspects of living systems that mechanistic thinking obscures. To show why the thing-process distinction is an important one, I first explicate the difference between substance and process ontology, secondly point out why a substance ontology does not hold in the cases of both organisms and music, and thirdly compare the ontological commitments of both machine and musical metaphors. I argue that understanding organisms as musical performances can capture better the relationship between change and stability in living systems, invites questions about the relative timing of events and processes, and can hence be heuristically and theoretically productive.

2 Metaphors and Science

Metaphors are still commonly thought of as figures of speech, used for rhetorical purpose only.[3] This section reviews several main arguments against such a view, and understands metaphors rather as *modes of reasoning* in which we equate two concepts in order to explore the one, the target domain, in terms of the other, the source domain. I may, e.g., use the concept of money to understand that of time to say that 'time is money;' one can 'spend it well' or 'waste it.' In science then, metaphorical reasoning may be used in a variety of circumstances: to make understandable a scientific concept, to explore and ask questions about phenomena and construct explanations. Consider one way in which we talk about cells in a body, which we say 'communicate' with one-another; one cell 'receives' the other's 'signal' and 'responds.' Accordingly, we may explain aberrations by suggesting that one cell 'failed to communicate.'

There exist different approaches to more sophisticated accounts of why such statements are instances of metaphorical reasoning, and how they function in science. In section 2.1 I outline Max Black's interaction-view of metaphor, and trace it into the Conceptual Metaphor Theory developed by George Lakoff and Mark Johnson. The landmark studies by Black, Lakoff and Johnson instigated a lineage of work in the philosophy of language and cognitive-linguistics that firmly opposes a view of metaphors as 'poetic language' that serves only poetic, rhetorical or at best pedagogical functions – but certainly not rational enquiry, understanding or explaining. Growing support for the idea that metaphors are aspects of thought which manifest themselves in different forms must clearly raise questions about their importance in the production, establishment and continuation of knowledge. In section 2.2 I will thus discuss a parallel lineage of work in the history and philosophy of science which raises these questions. I focus especially on the life sciences, which have been studied particularly well through analyses of the metaphors involved in theoretical discussions.[4]

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[3] See e.g. the Wikipedia entry on 'Metaphor.' Since 2008 there is a separate entry 'Metaphor in Philosophy,' which discusses some of the literature that is more in line with the view presented in the present paper.

[4] There are two very interesting, more recent developments in metaphor research, both in scientific contexts an outside of it: the *embodiment* of metaphorical reasoning, and the *multi-modal* nature of metaphorical expression. These I will not consider here, for they do not bear directly on my comparison between machine and music metaphors. Mark Johnson's book *The Body in the Mind* (1987) is the classic source for the idea that there are 'primary metaphorical concepts' which are grounded in embodied

2.1 What is a metaphor

Max Black (1954) distinguishes two traditional, and limited, views of metaphorical language and suggests a complementary third. The traditional views rest on a distinction between 'literal' and 'metaphorical' language. In what he calls the *substitution view of metaphor*, a metaphorical expression is one that can be substituted by the literal expression, and is not crucial to conveying the meaning of the statement. In Black's example – 'the chairman ploughed through the discussion' – the expression 'ploughed through the discussion' can be replaced by something like the expression 'the chairman dealt summarily with objections.' The former expression is the metaphorical one, which works because "an intelligent hearer can easily guess what the speaker had in mind" (Ibid., 278). A special case of the substation view is the *comparison view of metaphor*, which is the view that a metaphor essentially contains a comparison, which the reader must unpack as a puzzle, and which can then be substituted by the spelled-out literal expression of the comparison. Black's example is the expression 'Richard is a lion,' which on the comparison view of metaphor conveys meaning to the reader by first being unpacked as 'Richard is *like* a lion' after which to 'lion' is attributed a characteristic of 'lions' that appears to the reader congruent in the context in which the expression appears: 'Richard is *like* a lion (in being brave),' that is to say 'Richard is brave' (Ibid., 283).

The problem that Black has with these two views is that they suppose some clear connection between the literal expression and the metaphorical one, a *simile* between the two that should exist prior to the application by a writer of the metaphorical substitution or comparison. "If this were so, *similes* might be governed by rules as strict as those controlling the statements of physics" (Ibid., 284). Roughly, such connections could be made, such as when we explicitly talk about something using a common name, such as using 'Hollywood' to refer to American film-industry. Those forms of speech, in which a singular[5] comparison is made that could be made explicit by substitution are

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experiences through 'Image Schema.' Related work in science studies can be found in Natasha Myers' work on embodied reasoning practices among crystallographers (Myers 2006; 2015). For research into the idea that metaphors are expressed not only in language, but also in gestures (see Myers work), sound and image, Forceville and Urios-Aparisi's edited volume *Multimodal Metaphor* (2009) is a prime source of reference. So-called 'visual metaphors' in the sciences that have received particular attention are the various landscape images, such as fitness landscapes and epigenetic landscapes (Baedke, 2013; Baedke and Schöttler, Forthcoming; Fusco et al., 2014).

[5] It should become clear from my summary of the conceptual view of metaphor, below, why it is significant to make this distinction between 'singular' and multiple-reference comparisons. To be short, a

called metonyms.[6] But in many instances where one thing is talked about by comparison to or in terms of something else, there is in fact no plain language that can substitute the metaphorical expression and convey the same meaning. In such instances, metaphors work precisely by actively creating a meaning that cannot be captured by 'direct' language; the meaning of such a metaphorical statement is the result of the 'interaction' between thoughts of the two different things that are combined in the particular statement. This is what Black calls the *interaction view of metaphor*.

In the interaction view, "a metaphorical statement has *two* distinct subjects – a "principle" subject and a "subsidiary" one" (Ibid., 291). Consider the phrase 'man is a wolf.' Here, 'man' is the principle subject and 'wolf' the 'subsidiary' one. The principle subject acquires a meaning by being constructed by the reader in terms of the 'common characteristics' associated with the subsidiary subject. In the case of 'man is a wolf,' this means that the reader will think of those characteristics of a 'man' that are like the characteristics commonly associate with 'wolf,' and allow those corresponding, what Black calls, 'commonplaces' to 'organize' the entire principle subject. In this way, the metaphor highlights certain aspects of the principle subject (man), while obscuring others. At the same time, it relies on only a limited set of associations with the subsidiary subject (wolf) to do this, meaning that the subsidiary subject too is being highlighted in certain respects and obscured in others. For instance, the meaning of the metaphor 'man is a wolf' may change according to the cultural context in which it is used, because a person in one context may have a different set of commonplace associations with wolf than a person in another context. If in one cultural context wolves are commonly associated with notions like "fierce, hungry, engaged in constant struggle, a scavenger, and so on" (288), then a reader of the metaphor will construct a different meaning of what man is than a reader from a cultural context in which wolves are commonly thought of as "incarnations of dead humans" (Ibid., 287).

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multiple-comparison is on in which the comparison is grounded in a metaphorical concept and invokes a number of additional possible comparisons, whereas a singular comparison does not do this.

[6] This portrayal of metonymy is probably too simple. Metonymy and its relation to metaphor has received plenty of attention in the cognitive-linguistics literature. But for the present purpose, I do not think it will be productive to problematize this definition of metonymy and provide a more nuanced account, because much of what is involved in such accounts of metonymy resemble greatly those of metaphor. It will perhaps suffice to say that metaphors are *conceptually generative* of comparisons between the two objects of reference, whereas metonyms are *symbolical representations* of an object of reference.

A crucial difference between the first two views of metaphor, and Black's interaction view, is the importance of metaphors in *creating* meaning, and the reader's role in doing the creating. In the substitution view and the comparison view, a metaphor is entirely a phenomenon of language, a play of words for aesthetic and rhetorical purposes, and not crucial to conveying meaning. In the interaction view, a metaphor is instrumental in creating meaning: "This use of a "subsidiary subject" to foster insight into a "principle subject" is a distinctive *intellectual* operation" (Ibid., 293). "One of the points I most wish to stress is that the loss in such cases [where a translation of the metaphor is given in more 'literal' statements, that supposedly explicate its full meaning] is a loss in *cognitive* content; the relevant weakness of the literal paraphrase is not that it may be tiresomely prolix or boringly explicit – or deficient in qualities of style; it fails to be a translation because it fails to give the insight that the metaphor did" (Ibid., 293).

While Black makes a move away from seeing metaphors as poetic language that can be unpacked in literal statements, the interaction view of metaphor still treats metaphors as *special* instances of language use. This 'specialness' of metaphors and their application were swept off the table by George Lakoff and Mark Johnson in their book *Metaphors We Live By* (1980). Lakoff and Johnson present elaborate exemplary support for the idea that metaphors are central to the ways in which we not only talk about, but experience and understand the world. Their claim is three-fold: 1) metaphors are conceptual equations of two domains of knowledge, 2) human thought processes are metaphorically structured, and 3) this structural hierarchy of metaphoric thinking is grounded in personal experience through 'primary metaphors.' This thesis is known as the Conceptual Metaphor Theory (CMT).

CMT is similar to Black's interaction view in many respects. It refers to the 'principle subject' – that which we seek to understand – as the 'target domain,' and refers to the 'subsidiary subject' – that through which we understand – as the 'source domain.' In the interaction view, a metaphor organizes, "filters and transforms" (Black, 1954, 289). In the conceptual view it 'maps' and 'structures' (Kövecses, 2010, 7-9). But the important difference is that in CMT, metaphors are in the first place conceptual, and are centrally involved in structuring everyday experience, understanding and actions - indeed, that human thought processes are 'metaphorically structured.'

Along the lines of CMT, metaphors work as follows. A *metaphorical concept* is what *underlies* numerous *metaphorical expressions*. This metaphorical concept mediates a constant going back and forth between *source* and *target domain*, by means of which we create *correspondences* of *elements* in either domain. Creating these correspondences allows us to talk about the target in terms of the source in a way that makes sense. This works, in the first place, when the source domain is a conceptual domain that we think to understand well, while the target domain is a conceptual domain which we think to understand poorly, and want to understand better. A classic example, indeed the first example given in *Metaphors We Live By*, is the metaphorical concept ARGUMENT IS WAR,[7] which underlies many common ways of talking about an argument. Here, the source domain is 'war' and the target domain 'argument,' and can entail linguistic expressions like:

> "Your claims are *indefensible*.
> He *attacked every weak point* in my argument.
> His criticisms were *right on target*.
> I *demolished* his argument.
> I never *won* an argument with him." (Ibid., 4)

The linguistic metaphorical expressions in italics cannot be replaced by a more literal phrase without a loss of meaning, because they construe a multiple-comparison relation between for example a claim and its defensibility. Namely, by invoking the conceptual metaphor that underlies the phrase, we immediately are able to move between the two domains to set up additional correspondence that allow us to work with the concept which we are dealing with (having an argument, in this case). "It is important to see that we don't just *talk* about arguments in terms of war. We can actually win or loose arguments. We see the person we are arguing with as an opponent. […] Many of the things we *do* in arguing are structured by the concept of war." And so, someone from another cultural environment, in which arguments are conceptually viewed as something else – let's say a dance which we perform together - would not only talk about arguing differently, they would have a different experience

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[7] Writing the metaphorical concept in capital letters appears to be common practice in work on conceptual metaphor across many fields. I conform to this practice throughout the rest of this paper.

and understanding of what it means to argue. And "*we* would probably not see them as arguing at all" (5).

Lakoff and Johnson conclude that "the essence of metaphor is understanding and experiencing one kind of thing in terms of another," in particular when the 'one kind of thing' which we understand and experience in terms of the other is seen as 'abstract.' Two aspects of CMT need to be pointed out in particular: *organization* and *partiality*.

In using a metaphor, we *organize* a structure of terms and relations from the conceptual source domain onto the conceptual target domain. When we think that LIFE IS A JOURNEY, we say that the future is the road ahead, in which case we 'project' the notion of a road from the context of a journey onto that of time from the context of life. Interestingly, there may, on the one hand, be elements to the target domain which we identify prior to the projection (like 'time' and 'future; in the previous example), and which we conceptually seek to make sense of. On the other hand, there may be elements to the target domain that we do not identify beforehand, but which are created by applying the conceptual metaphor: we can say that LOVE IS A BUILDING, which needs a strong foundation – what that foundation *is* in the context of a relationship need not be clear yet, but we might begin to wonder what could be its correspondence, and consequently identify it.

In this way, metaphorical concepts 'highlight' certain elements in either domain while at the same time 'obscuring' others: metaphorical concepts create a *partial* understanding. That is, not every way in which we experience or talk about about the source domain is used to talk about and experience the target domain; and in the same way, not everything that could be identified in the target domain is taken up in the metaphorical expressions that derive from the metaphorical concept. Metaphorical concepts allow for an overlap (the 'highlighted' part) between source and target, within which elements from either domain have been organized to construe a way of talking that makes sense in both directions. Importantly, there always remain parts of either domain which have not been organized along the metaphorical concept (the 'obscured' part). In principle, if source and target could be completely organized in terms of each other, they would effectively be the same conceptual domain.

Precisely because metaphors allow us to make sense of only a part of the target domain, there can be a *multiplicity* of metaphorical concepts for the same target domain.

Next to the above metaphor LOVE IS A BUILDING, we may say LOVE IS A JOURNEY and LOVE IS A NATURAL FORCE to create meaningful expressions, like:

> Our relationship is at a *crossroads*
> I was *overwhelmed* by my feelings for her

In conclusion, *metaphors* are *conceptual* equations of a *source domain* which we understand well and a *target domain* which we seek to understand better. When talking about a 'metaphor' I am thus really talking about the 'metaphorical concept' which underlies possible metaphorical expressions. With a metaphor we *organize* elements from source and target, and consequently *understand the one in terms of the other*. A metaphor *mediates* a continuous process of exploration of both target and source, but it is always only a *partial* exploration of a target, highlighting certain elements while obscuring others.[8]

2.2. Metaphors and Science

How do metaphors matter to scientific research, and how are they used? From the perspective of CMT they have a necessary place in reasoning, which in turn has an obvious place in scientific research. As Evelyn Fox Keller put it: "scientific research is typically directed at the elucidation of entities and processes about which no clear understanding exists, and to proceed, and scientists must find ways of talking about what they do not know […] they need to invent words, expressions, forms of speech that can indicate or point to phenomena for which they have no literal descriptions" (Keller, 2002, 118).

A useful distinction to start characterizing these 'ways of talking' is between *rhetorical*, *heuristic* and *theoretical* functions of metaphors (Bradie, 1999). Rhetorical metaphors serve as illustrations that highlight relevant aspects of the target domain, e.g. in the context of teaching, but they do not- or are not intended to further a research; heuristic metaphors are explorative, as they invite questions about the target domain

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[8] I do not distinguish very sharply between metaphors and analogies: I take analogies to be the correspondences between elements in the source and target domain – analogy-making is thus part of the process of metaphorical reasoning. There is of course much work on so-called 'arguments by analogy' (see e.g. Juthe 2005), but here I will not discuss this, as the literature on conceptual metaphor suffices for the present purpose.

and may inform methodological strategies; theoretical metaphors structure the very answers of research question, frame the kinds of explanations that are given and introduce language from the source domain to our explanations of the target. These functions can overlap, and are not mutually exclusive as certain metaphors can fulfill multiple functions at the same time.

The idea that models, analogies and metaphors are not just of rhetorical and limited heuristic importance to theory formation, but are constitutive of theory, goes a long way; and I am not going to trace that history, but will give three telling examples. In 1912, phyiologist D. Fraser Harris got published a short article in Science, titled "The Metaphor in Science." In it, he recounts a number historical occasions in which "an idea at first represented by some metaphorical expression became in course of time a concrete existence" (Ibid., 263). Such as the case of Lavoisier, who "had not isolated oxygen by a stroke of genius and then proceeded to study the properties of the new chemical product" (Ibid., 263), but had postulated an 'oxygine principle' on the basis of acidity-exchange reasoning about phlogiston. Or the case of the circulation of the blood, which Harvey described through reasoning with circular movement: "I began to think whether they might not be motion (or a movement), as it were, in a circle. Now this I afterwards found to be true" (Ibid., 264). In 1930, Sigmund Freud won the Goethe Prize for literature; certainly he knew and was able to exploit the rhetorical power of metaphors. Yet no less did he consider them fundamental to his theoretical work: "In psychology we can describe only with the help of comparisons. This is nothing special, it is the same elsewhere. But we are forced to change these comparisons over and over again, for none of them can serve us for any length of time."[9] Similarly, Physicist N. R. Campbell rejected the idea that metaphors are mere 'aids:'

> "Analogies are not 'aids' to the establishment of theories; […] It is often suggested that the analogy leads to the formulation of the theory, but that once the theory is formulated the analogy has served its purpose and may be remove or forgotten. Such a suggestion is absolutely false and perniciously misleading."[10]

Mary Hesse was among the first philosophers of science to really take up this point by Campbell, and develop it systematically. In her book *Models and Analogies in Science* (1966) she has argued that the "deductive model of scientific explanation should

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[9] Quoted in Draaisma, 2000, p.8

[10] quoted in Hesse, 1966, p.4-5

be modified and supplemented by a view of theoretical explanation as metaphoric redescription of the domain of the explanandum" (Ibid., 157). Hesse works this out on the basis of Max Black's interaction view of metaphor, whose major contribution, she notes, has been the insight that metaphors *create* new meaning separate from the meanings of either the target or source domain; the metaphorical conception of target in terms of source is a necessary structure underlying meaningful reasoning. Thus, "nature becomes more like a machine in the mechanical philosophy, and actual, concrete machines themselves are seen as if stripped down to their essential qualities of mass in motion" (Ibid., 163). When the target domain of a metaphor is the empirical phenomenon we wish to explain, this means that it has been partially *redescribed* in terms of the source domain, and we can use terms from the latter to formulate an explanation that applies "with approximate equivalence" (Ibid., 173) to the former. In that way, "what gets explained is not the original phenomenon P but a "more acceptable" redescribed phenomenon P'. The explanans E entails [Descriptive statement] D', not D" (Bradie, 1999,128). Such an explanation can be counted as a theoretical explanation if it has not been falsified to date, and if the explanans entails further predictive statements (Ibid., 127).

Hesse points to another characteristic of analogy-making, one that we can use to distinguish between the different functions of metaphors. As we saw earlier, the two conceptual domains that are equated in a metaphorical concept do not have all features in common, but the target is *organized* in terms of the source:

"When we take a collection of billiard balls in random motion as a model for gas, we are not asserting that billiard balls are in all respect like gas particles, for billiard balls are red or white, and hard or shiny, and we are not intending to suggest that gas molecules have these properties" (Hesse, 1966, 8).

Those disanalogies between the two domains, Hesse calls *negative analogies*. Then there are features which we know already that both domains share – "motion, and impact" (Ibid., 8) – which she calls *positive analogies*. Lastly, there are features of the source domain of which we do not know yet whether the target has them, and these are the *neutral analogies*. In the present example these would be the principles of mechanics that we use to make predictions about the behavior of billiard balls; whether these principles can also predict the behavior of gas particles is for the researcher to find out.

We can relate this schema of analogy-making to the different heuristic functions of metaphors in scientific research. Those metaphors that exploit only their positive analogies are used in rhetorical contexts, while those metaphors that additionally suggest neutral analogies serve in the first place a heuristic function, and may turn out to function theoretically. Rhetorical metaphors are usually formulated *after* a process of prior conceptualizations of the target domain, while heuristic and theoretical metaphors are formulated *during* the research process (Baedke and Schöttler, Forthcoming).

Let us turn to biology. Of particular use in modern biology, serving rhetorical, heuristic and theoretical functions at the same time, are machine metaphors (Nicholson, 2012, 2013, 2014). Thinking about phenomena of life through analogies with human artifacts, analog and digital machines such as clocks, steam engines, or computers, has proven to be enormously productive. The Cartesian *mechanicist philosophy* of Descartes underlay the work of many influential biologists, such as Antoine Lavoisier, Herman von Helmholz, Wilhelm Roux, and Jacques Loeb, and today its most prominent expression is found in synthetic biology's mechanical engineering approach to creating cellular life. The mechanicist framework posits the existence of *machine mechanism*, "stable assemblies of interacting parts arranged in such a way that their combined operation results in predetermined outcomes" (Ibid., 153). A typical example is the cellular 'machinery;' something like a transmembrane 'pump' can be understood through investigation of its parts and mechanical capacities. At the same time there is the familiar, but more recently adopted biological notion of *causal mechanisms*: "A step-by-step explanation of the mode of operation of a causal process that gives rise to a phenomenon of interest" (Ibid., 153). We will come back to this three-partite distinction in part 4.4.

Evelyn Fox Keller (1995; 2002) has shown how explanations in 20th century genetics and developmental biology have depended on the productive use of the 'root metaphor' that ORGANISMS ARE MACHINES. Concepts like 'genetic program,' 'feedback' and 'switch' introduced new language with which to make sense of development: "All of these terms borrow from other domains [i.e. different sorts or aspects of machines], carrying meanings and explanatory functions employed in those other domains even when discordant, but they are now put to work in new contexts in ways that exploit both the consonance among these other meanings and the tensions evoked by their various kinds of mutual discordance" (Keller, 2002, 113-4). An example of metaphorically derived terms, introduced into genetics, with discordant meaning are those of 'program' and 'information.' To speak with Francois Jacob, who introduced the term genetic program, "the programme is a model borrowed from electronic computers, it equates the genetic material of an egg with the magnetic tape of a computer. It evokes a series of operations to be carried out, the rigidity of their sequence and their underlying purpose" (Jacob, 1973, 9).[11] Many of the ways in which we understand digital machines are used to understand heredity and the control of development, which "is described today in terms of information, messages and code" (Ibid., 1). The notion of information was borrowed from Claude Shannon's information theory. If even in the 1960s it was recognized already that Shannon's understanding of 'information' was not applicable entirely to the DNA, it remained in use because it was an immensely powerful conceptualization of DNA in the explanatory framework of geneticist. For even though there was still no answer to the question of *which* and *how* particular genes produced the phenotype, it could answer the question conceptually and set an agenda for even further possible ventures: "Embryonic development [must] be an unfolding of pre-existing capabilities, and acting-out of genetically encoded instructions" (Keller, 1995, 20). Namely, it was out of the question that genes were the "primary internal agents controlling development" (Keller, 2002, 125), but how hereditary factors, and later the DNA, should be studied to explain development, and conversely how genes function in explanations of development "would seem to depend on what kind of entity the gene is taken to be" (Ibid., 116). Molecular genetics came to understand the gene as a piece of coded information that instructs development in programmatic fashion.[12]

As an example of one of the 'operations to be carried out,' we can look at how the notion of message had become metaphorically applied. The context here is the problem of how the DNA molecule specifies the structure of proteins, i.e. how it contains a determining code. In their 1961 paper "Genetic regulatory mechanisms in the synthesis

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[11] The term, 'programme,' first appears in 1961, simultaneously in the work of Jacques Monod and Francois Jacob – in the last sentence of their famous operon-model paper – and Ernst Mayr: "We can use the language of information theory [...]. The functional biologist deals with all aspects of the decoding of the programmed information contained in the DNA code of the fertilized zygote. The evolutionary biologist, on the other hand, is interested in the history of these codes of information and in the laws that control the changes of these codes from generation to generation" (1961, 1502).

[12] The digital machine metaphor underlying 'program' and 'information' provides both a causal mechanism (CM) explanation of development as well as an understanding of the process of genetic control as a machine mechanism. This too will become relevant again the section 4.4.

of proteins," Jacob and Jacques Monod suggest that the transition from structural gene to protein "must involve a chemical intermediate [which] we shall call the structural messenger" (Ibid., 319). Identification of "a small fraction of RNA [which] does meet all the qualifications listed above" leads them to suggest an appropriate name: "which we shall designate "messenger RNA" or M-RNA" (Ibid., 350). This small example shows how the digital machine metaphor is used to point to certain neutral but possibly positive analogies with information processing. In a similar way, the notion of program is used to suggest a possibly positive analogy with phenotypic control. Namely, while not every phenotypic trait need directly be coded for by the genes, the *flexibity* of phenotypes according to environmental conditions *is* directly determined by the program (Jacob, 1973, 10). Accordingly, the program metaphor frames the relevant questions which, once answered, lead to an explanation of the phenomena of development: "on the one hand, it is necessary to analyze the structure of the programme, its logic and its execution; on the other, to examine the history of programmes, their drift and the laws governing their changes throughout the generations in terms of ecological systems" (Ibid., 8; see also Mayr's programmatic statement in footnote 10).

In conclusion, metaphors can have rhetorical, heuristic and theoretical functions. The distinction rests on the use of positive, negative and neutral analogies, which can be made when two conceptual domains are equated in a metaphorical concept. Positive analogies are those known similarities between source and target on which the metaphorical concept initially relies; negative analogies are those known *dis*similarities between source and target which remain excluded from the metaphor; neutral analogies are features of the source domain of which it is not known whether they are positive of negative analogies. Rhetorical metaphors are *illustrative*, by using only positive analogies to construct a way of talking about the target domain that highlight important features. In heuristic metaphors we suggest that certain neutral analogies can help us to further our understanding of the target domain. Theoretical metaphors are *explanatory*, when they structure a description of the target domain as if it actually were the source domain. Progress in understanding involves the introduction of new metaphors that refine the framework of positive analogies.

3 A Musical Conception of the Organism

We have seen how machine metaphors can serve as crucial heuristic and theoretical tools in biological research. Problems arise, however, when this one metaphorical conception comes to dominate a field, and when that which the metaphor highlights is taken as the entire picture of a target phenomenon. Especially in the cases developmental and evolutionary biology, machine metaphors such as the 'genetic program' and 'reverse engineering' have received sustained critiques (Nijhout, 1990; Lewontin, 1996; Oyama, 2000; Longo and Tendero, 2007; Nicholson, 2013; Pigliucci and Boudry, 2014).

The notions of 'genetic program' and 'blueprint' entail three theses about the role of DNA in development: *genetic animism* – the genome controls development –, *gene-centrism* – only knowledge of the genes matters for an understanding of development –, and *neo-preformationism* – the fertilized zygote already contains the entire program for development, and can thus be marked as the starting-point of development (Nicholson, 2014, 165). The comparisons to music at issue here go to show the inadequacy of these theses. They can effectively be read as voicing the ideas of the Extended Synthesis, Developmental Systems Theory (DST) and (Eco-)Evo-Devo.

Interestingly, Ernst Mayr, central to the formulation of much program-thinking, himself once used a musical metaphor to illustrate the three program theses:

> "Development, it seems to me, can be compared with the activities of a symphony orchestra. The musical score tells the musicians what to produce and when. The conductor reinforces and synchronizes the 'turning on' and 'turning off' of the activities of the individual musicians. […] The activity of an orchestra, including that of its conductor, is just as much controlled by the score it is playing as the development of an organism is controlled by its genetic program" (1997, 379).

In most of the examples that follow, the DNA is also compared to a musical score. But unlike Mayr, they recognize that *something* happens between score and music what makes that music is always more than the mere execution of a program.[13]

3.1 Development as Musical Performance

Before dissecting these musical metaphors, and to do justice to the ways in which these various authors attempt to talk about genes, development, organisms and evolution, I will first quote them at length.

Eva Jablonka and Marion Lamb, in *Epigenetic Inheritance and Evolution: The Lamarckian Dimension* (1995), write:

> "If the score represents hereditary information in DNA, the phenotype is a specific interpretation of this score at a certain time by certain artists. The interpretation does not affect the score. However, if there is another transmission system – recordings – through which a particular interpretation can be transmitted from generation to generation along with the written score, the situation is rather different. There can then be evolution of interpretations of the score, based on the influence that one interpretation has on subsequent interpretations, and that these have on still later ones, and so on. Both the phenotype (the present interpretation) and the genotype (the written score) influence subsequent interpretations."[14]

Evelyn Fox Keller contributes another line to this train of thought:

> "Not only does the phenotype (the present interpretation) influence subsequent determinations through epigenetic inheritance, but it can also participate in the modification of the genotype (the written score) itself – as if, e.g., marks were inserted in the score in response to current interpretations" (1998, 114)

Jason Scott Robert suggests yet a further transformation of this idea:

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[13] Performing a score with a computer, for example, is perfectly possible and not difficult at all. However, having a computer perform the score in such a way that it actually sounds like a human performer plays the score, i.e. an *expressive* performance, is an exceedingly difficult task. In fact, there is presently much attention among researchers in Artificial Intelligence and Computational musicology into computer-generated expressive performance. There also exists an annual international competition of so-called Performance Rendering Systems, Rencon, in which different programs compete for the most expressive performance of a musical score in front of a human audience.

[14] Quoted in Keller, 1998, 114

> "There is neither score nor recording except in performance; the orchestra and conductor together create the score anew with each performance. In other words, epigenesist is constitutive, not additive" (2006, 74).

Denis Noble makes the same point, in a slightly different way:

> "There would be no need for a complete map of the organism, just as a musical score is not a complete miniature map of the music itself.
> "If there is a score for the music of life, it is not the genome, or at least not that alone" (2006, 45).

Rather than orchestra and conductor, Patrick Bateson is thinking of jazz in particular:

> "To use a different metaphor, development is not like a fixed musical score that specifies exactly how the performance starts, proceeds, and ends. It is more like a form of jazz in which musicians improvise and elaborate their musical ideas, building on what the others have just done. As new themes emerge, the performance acquires a life of its own, and may end up in a place none could have anticipated at the outset. Yet it emerges from within a fixed set of rules and the constraints imposed by the musical instruments" (Oyama et al., 2001, 157).

The idea that a performance of music involves an *interpretation* of- and *improvisation* on the written score is made more explicit in Miquel Porta's short narrative:

> "The genome nucleotide sequence is the score of a jazz composition. First, the jazz musician learns how to read and to play the score, and does so embedded in a sociocultural environment, and grows with music and musicians and partners of all sorts. Though her endowment and talents count, so do her colleagues, experiences, and intuition: the result of such interaction is seldom predictable. Then, all over her life she continues to learn: to master technique—certainly—

> but above all, to express her emotions and ideas among the many treasures that music holds. The genome is thus like the innumerable scores that a jazz aficionado would play during all her life, some with great fidelity to the original musical text, many just—but deeply—inspired by it, still many others almost totally invented, whether improvised or consciously crafted. Surely the music that she expresses stems from the scores (through a marvelously complex process); but well beyond technique and script, every instant the unique music expresses what the musician knows, feels, and wishes to play. (Once, the origin of the music is a scent she smelled in infancy; once, a recent love loss; often the 'source code' is unknown.) And the music grows and evolves: with time—and, much more, with the people and places where it swells and flows. Stemming from the score. Sensitive to the other musicians with whom she plays. Delicately responsive to the audiences to whom and with whom she feels, every time of her lifetime" (2003, 30).

But certainly the most elaborately developed analogy with musical performance is found with Scott Gilbert and Jonathan Bard (2014):

> "The organism does not inherit a 'program' as much as it inherits DNA and a cytoplasmic interpretation device. The same programmed music score can be interpreted in numerous ways by different orchestras. Every performance is different, even from the same score and the same orchestra.
> "So there must be interaction between score and instrument (and orchestra, more largely), and there must be interaction between DNA and transcription factors. That the performance of a phenotype depends on its wider context has been long known by embryologists.
> "Any theory of the development of a tissue involves the prior history of that tissue, knowledge of the tissue's environment and a description of the geometry of that tissue's environment. The music is written in several parts.
> "In music theory, a chord is a 'simultaneity', a series of different notes, each of which is played at the same time as the other pitches of its group. Thus, a chord progression is called a 'succession of simultaneities'. Chord progressions are the homologies of music. They are the underlying unity amidst the apparent diversity. The I-VI-IV-V progression (e.g. C-Am-Dm/-G7) originated in Western

> music in the 40s. It is the underlying progression of Heart and Soul, The Way You Look Tonight, and hundreds of others. […] There are only so many chords that work together. It's not what's possible. It's what's compossible.
>
> "Evolution occurs by changing development. Improvisation – playing something novel with other musicians - is not complete freedom. Rather, it is the mutual understanding of the chord progressions. […] Each improvisation has to work within the musical context provided by the other performances. This is the mutually constructed niche that 'enables' the particular improvisation.
>
> "Each animal has most of the same notes. But it is where you play the notes (In combination with what other notes), how long you play them, and how loud you play the, that matter. Homologies are the chord progressions of evolution. Each species is its own song. Each individual is performance of the song, with its own idiosyncratic improvisation on the score.
>
> "Development is thus an ongoing performative act. It involves a score (DNA), an orchestra for interpretation (to choose what DNA is a gene, what the function of BMP4 is in any particular cell, etc.), and improvisation (regulating gene expression such that most knockout mice have minimally altered phenotypes; altering anatomy by changing gene expression patterns)."

3.2 Development as Musical Performance: a closer look

Musical scores do not correspond one-to-one with performed music. At least, there is always a degree of *interpretation* involved. With Jablonka and Lamb, the phenotype is always more than the straightforward expression of genes, it is the instantiation of "epigenetic processes such as chromatin marking and genomic imprinting" (Robert, 2006, 74).

But this DNA-score comparison does not seem all that different: "they are still rooted in a static conception of information. The DNA becomes a musical score instead of a linguistic text [or source code] and can be interpreted or used to govern an orchestration. But it is not an interactive or dynamic image" (Turney, 2005, 809-810). In Jablonka and Lambs comparison, a score *precedes* a performance, and interpretation works with it. Other examples of musical metaphors for the genome reverse this order. Robert (2006) suggests that any 'score' is really the *result* of the performance, rather than its precondition: "There is neither score nor recording except in performance; the orchestra and conductor together create the score anew with each performance. In other words, epigenesis is constitutive, not additive" (Ibid., 74). The important difference in emphasis is between DNA and genes; while the DNA molecule may be there prior to development, "genes themselves do not precede the cell organism."

This is also how Gilbert and Bard (2014) use the notion of interpretation. If genes are meaningful pieces of DNA, i.e. with causal power, then this meaning has been actively created by the context: "Only certain regions of the DNA are constructed into genes, and different regions of the genome can be genes in different cell types. Note that the 'gene' is a higher order structure than the DNA, and that the interpretation of 'what is a gene' is done by the cell, an even higher order structure." In the same way, Porta (2003) suggests that the genome is like all the "innumerable scores that a jazz aficionado would play during all her life" – namely, some 'innumerable' sum total of all the ways in which DNA sequences throughout the cells in the living system have been constructed into genes.

The notion of interpretation thus expresses the reciprocal causal relation between parts and wholes in organisms: not only do we need the parts to understand the whole, but we equally need the whole to understand the parts. This process of interpretation involves an 'interpretation device,' as Gilbert and Bard put it, a higher order structure to do the interpreting. "We inherit much more than our DNA" (Noble, 2006, 41), we inherit a host of molecular machinery as well as range of environments in which these processes occur. Environments which are at the same time *made up* of other 'musicians' – other cells in the same tissue, or symbiotic cells – who engage in their own musical performance, as well as *part of* the very musician them self who does the interpretation of one particular score: "the music is written in several parts" (Gilbert and Bard, 2014, 139).

Improvisation is presented as freedom within bounds. With Bateson these are "a fixed set of rules and the constraints imposed by the musical instruments." These rules are particular sequences of events that allow for- or make up particular developmental pathways. Improvisation is the ability to find alternative forms of these sequences: "if the normal developmental pathway to a particular form of adult behavior is impassable, another way may often be found" (Oyama et al., 2003, 156). This is similar to Gilbert and Bard suggestion that 'compossible' simultaneities of tones in chords, and of chord progressions in songs are the rules in music on the basis of which an improviser can play around. Evolutionary homologies and patterns of gene expression are such compossible simultaneities of tones and chord progressions. Importantly, it is again only within a context that combinations of simultaneities and chords are compossible – a context which is actively constructed by musicians in the form of an ensemble, and by organisms in the form of niches. The notion of improvisation thus points to certain fixed patterns of change, "the underlying unity amidst apparent diversity."

By alluding to the crucial importance of interpretation and improvisation in the performance of music, these analogies point to the inadequacy of the program view of development. Musical performance is a creative process, an "ongoing performative act," in which many relations are organized in an open-ended fashion. This process is *not* fully pre-determined and *not* controlled by a representational agent like a score. Towards highlighting these features of development, the analogy with music is very effective.

3.3 Music versus Program: so what?

So can we say that there is here a *musical metaphor* that could serve as an alternative to the program metaphor? I suppose the quick answer is yes. But the interesting question is of course, in what way – as a rhetorical metaphor or as a theory-constitutive metaphor. The former appears to be the authors' actual intention. For example, to Miquel Porta, his musical analogy is useful when it comes to explaining "to non-specialists – and to ourselves – […] the wider meaning of research findings on the human genome sequence" (Porta, 2003, 29). Denis Noble too is quite clear that his book *The Music of Live* is meant as a polemic, and "like a polemicist, I make free use of metaphors" (2006, xi). Scott Gilbert told me that he would use this metaphor to explain to undergraduate students how identical twins are "two performances of the same score."[15] Porta, Noble and Gilbert at least think that they *not* in the business of formulating a theory-constitutive alternative to the program metaphor.

But the authors need not be aware of such a possible use of their comparison to music. The question to ask is whether the musical metaphor for development suggests positive or neutral analogies, i.e. whether it relies only on *existing knowledge* of both domains or whether it also suggests *possible understanding* of the target in terms of the

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[15] Personal communication

source. As I showed earlier, the program-metaphor is not only an important rhetorical tool to the reductionist project, it is a theory-constitutive metaphorical conception of development precisely because it explores neutral analogies.

Upon first inspection, the musical metaphor seems to rely on positive analogies, as it compares, e.g., interpretation or improvisation to particular biological processes. Processes which are perhaps understood even better than the musical concepts themselves. We could even read the analogy the other way around, using what is known about epigenetic mechanisms, context-dependent gene-expression patterns or protein function to understand interpretation and improvisation better – illusive processes themselves, about which neither musicologists nor psychologists nor cognitive scientists agree very much.

But this need not be a problem. The ambiguity of meaning in these cases might in fact be productive, as it are the "cognitive tensions, generated by ambiguity and polysemy" which make certain concepts attractive and gives them explanatory force in various contexts – such has arguably been the case with the likes of 'gene-action,' 'feedback,' 'genetic program' and 'positional information' (Keller, 2002, 7, 14). 'Interpretation' could be applied differently in the context of a biochemical question or in that of a physiological question, while at the same it emphasizes in both the context-dependency of a phenomenon.

Even though the presently explored comparisons to music make mostly positive analogies, there is one important aspect in which the musical metaphor is very different from the machine metaphor. These musical metaphors equate a source and target domain on the basis of a resemblance that is fundamentally different from that on which the program-metaphor is based; the latter understands organisms as *things,* while the musical metaphor understands them as *processes*. Although several of the authors discussed here emphasize that their musical metaphors place an "emphasis on processes" (Gilbert and Bard, 2014, 139), because "music also is a process, not a thing" (Noble, 2006, 143), none of them work out this point. It is however a very interesting point, and one that resonates with recent attention in history and philosophy of biology to process philosophy and Organicism (e.g., Dupré, 2012; Nicholson and Gawne, 2015). I will give it a close look here, and elaborate on the musical metaphor along processual lines.

4 Processes, Organisms and Music

What is the difference between saying that organisms *are* things and that organisms *are* processes? And why should we prefer one over the other? In this section, I will first make some preliminary, general remarks on this distinction between things and processes, and secondly review why biology may be served better by a process ontology. In a third step, I will show how thinking about music can clarify some central ideas of process philosophy in such a way that it may be usefully applied to the example of development.

4.1 Process ontology

The distinction between process and 'thing,' or substance, is an ontological distinction, one between two categories that function in metaphysical questions about the nature of reality. Important ontological categories that are important now are substance, process, event, and kind. A question like 'is an organism a process?' asks to which category organisms belong, and is thus an ontological question.

There exists no unified doctrine of process philosophy (Rescher, 1996, 32-33), nor should we expect there to be one on the basis of this most general Heraclitean principle associated with process philosophy that 'all things flow.' Process philosophy is perhaps best understood as a tradition of western metaphysics that positions itself diametrically opposite to substance-metaphysical systems, the dominant position in metaphysics in the Western tradition (Ibid., 4).

Substance metaphysics gives ontological primacy to substances, and suggests that other categories can be understood in terms of substances. Substances persist, i.e. are self-identical at various times, by possessing certain essential properties, i.e. properties that are the necessary and sufficient condition for their being that kind of thing. On this view, events and processes are changing constellations of- and interactions between substances. Process metaphysics on the contrary gives ontological primacy to processes, and sees substances as relatively stable stages of processes. Processes depend on change, but are not equivalent to change; they are best characterized as sequences of events.

Process philosophers, A. N. Whitehead most notably, have repeatedly introduced more process-oriented language, for they saw ordinary language, in which verbs relate the doings of nouns, as deeply embedded in substance-thinking. Yet, "Copernicans have not desisted from speaking of sunrises" (Rescher, 1996., 33), and process philosophy offers, in the first place, an alternative in emphasis and principle. It emphasizes becoming over being, activity over entity, process over product, change over persistence and novelty over continuity. We can distinguish between 'weak,' or epistemic, and 'strong,' or ontological, version of process philosophy. The weak version consists in the idea that an investigative orientation towards processes should always lead to a better understanding of natural phenomena. The 'strong' version insists that the weak version is right precisely because being *is* the process of becoming.

Process philosophy further, in principle, rejects the 'process reducibility thesis,' that processes can be reduced to an understanding of the 'doings of substances.' There are two general reasons to reject this thesis. The first is the predominance of *unowned* processes: activities that are clearly not the doings of a spatiotemporally identifiable thing, such as a thunderstorm or the spreading of a rumor or fire heating a pot of water. Secondly, substances are supposed to explain the doings of things by virtue of having certain dispositional properties. But those dispositions can only be determined by looking at what they do, i.e. what interactions there are between substances. This leaves the substances in and of themselves, apart from any interactions, as "bare (property-less) particulars" (Ibid., 48). A process ontology dissolves this problem by saying that things simply *are* their doings, and dismisses the need to identify some essential, non-relative property.

A further important difference between substance and processes lies in what they must explain. What needs to be explained from the substance point of view is change: how can there be change from stasis? From the process point of view, what needs to be explained are things: how can there be things from change? One small step toward tackling the second, process-problem is saying that there are never any unchanging things. Rather, what appear to be things are only relatively slower rates of change.

4.2 Biology and process ontology

Process-philosophical ideas have been woven into the fabric of biological thinking on numerous occasions. The Organicist biology developed by people such as Joseph Needham, John Scott Haldane, Joseph Henry Woodger, Ludwig von Bertalanffy and Conrad Hall Waddington, was deeply inspired by Whitehead's process philosophy (Nicholson and Gawne, 2015). More recent is the 'process-structuralism' developed by people like Stuart Kauffman, Brian Goodwin, Gerry Webster and Peter Saunders (Resnik, 1994). In recent years, process philosophy and biology have been brought together most prominently in the work of John Dupré (2008; 2012; 2013; 2014; Dupré and Guttinger, 2016).

Dupré specifically takes issue with the possibility that the hierarchy of typical biological things – from genes, to cells, organism, lineages and so on – could be understood as one of substances. Substances have essences, and concepts like gene and organism thoroughly resist any definition based on essential properties. Of particular difficulty are the indeterminacy of boundaries between individuals and the reciprocal causal relationship between any biological entity and its context throughout the entire organizational hierarchy.

For instance, the classical conception of gene, as the heritable causal determinant of a particular phenotype, cannot be coupled to a particular material entity like a stretch of nucleotide in the DNA; not even in as seemingly a clear-cut case of a double recessive disease like cystic fibrosis (Dupré, 2008, 25-6). Almost two-thousand, and counting, possible mutations in the base pair sequence of the CFTR-gene have been correlated to development of the disease, with varying degrees of severity (Bonini et al., 2015). If one possible variant of mutated CFTR can be pointed to as a cause of the complications under the name of cystic fibrosis, it is at least not the only. Also from molecular genetics perspective of genes, as direct structural precursors of proteins, there is no unique way in which one sequence of nucleotides can be pointed to as the material specification for a protein: there are many different ways in which the same sequence can result in different proteins, and in which different sequences can result in the same protein. Moreover, even the particular function of a protein cannot be determined solely on the basis of its structure, which is what the generally assumed sequence-structure-function (SSF) paradigm maintains (Guttinger, Forthcoming, 22). The particular chemical capacities of a protein to 'do' something, such as phosphorylating a substrate, can in practice only be understood in the context of the larger biochemical system of which it is part; phosphorylation is not a capacity that a kinase has because of its structure alone. Even the molecular structure that gives a kinase its functional capacity in the right context does not result simply from its amino-acid sequence. The formation of functional structures is the result of constantly changing interactions and 'repulsions' with other molecular structures in the environment. So the possibility of describing a gene-to-protein relation on the basis of molecular constitution seems meagre from many points of view.

'Moving up' the organizational hierarchy to organism, we run into similar problems. Organisms vary widely in morphology, physiology and ecology throughout their life cycle. Although we typically depict organisms in their adult form, that is only to take a time-slice of a lifetime's worth of continuous transformation, certainly not 'the whole picture.' Take the aphid *Parcletic cimiciformis,* which undergoes nine very distinct metamorphoses during its lifetime (DiFrisco, 2015, 25); which of these *is* the organism? Alternatively, could we point at the genome as that property of an organism which persists throughout its lifetime? As we saw above, this is difficult when there is no unique way of determining what the genome *is*. Which stretch of DNA comes to partake in protein synthesis, and which processes these proteins in turn partake in, depends on more than molecular properties alone. Genes are "higher order structures" (Gilbert and Bard, 2014, 130), so in this sense different cells in one multicellular organisms have different genomes. Complicating this problem even more is the deep symbiotic interconnectedness of microbial and host lineages that is found with almost all multicellular life forms (Dupré, 2012, 11). As a functional whole, the individual organism should be taken to include not only those cells that derive from the zygote, but also many lineages of microbial life-forms – bacteria, archaea, fungi and viruses – that form stable metabolic interactions with them at different times (Dupré and O'Malley, 2009; Dupré and Guttinger, 2016).

Organisms are not things in the sense of substances, because they do not persist by virtue of some essential properties. Nonetheless they certainly do *appear* to be stable things. A process-alternative does not reject the biological hierarchy of entities as such, but rather suggests that it is best understood as a hierarchy of relatively stable processes. And what is stable about an organism depends on the timescale at which one looks at it. Development is a relatively slow process compared to metabolism, while it is fast compared to evolution. In a medical context, a stage of the developmental process can be treated as a stable thing. In a developmental context these stages are only time-slices, and what is stable here is the sequence of functional events, the developmental process itself.

4.3 Music and process ontology

Thinking about music can help to clarify some of the above questions. For one thing, music has since long been considered to be the art of temporality *par excellence*, uniquely able to reflect on the elusive nature of time and change. The apparent paradox in music is that of "simultaneity in successiveness" (Carpenter, 1967, 59): on the one hand, there is a constant fleeting of successive musical events, while on the other, we can perceive some sort of wholeness to music. "By offering an example of temporally separated events that nevertheless are perceived to belong together and fit into an indivisible whole, music provides an actualization of identity amidst flux" (Taylor, 2016, 51). The point here is that, somehow, our aural perception of sounds can bring about a sense of shape and figure:

> "This occurs quite spontaneously with short musical units such as single notes, chords or small phrases, but we often experience larger blocks of music – a complete song or a movement of a piano – as 'objects' to the extend that we perceive them as unified or integrated in some significant way" (Butterfield, 2002, 332).

This is not some intrinsic quality that music has. Rather, it is what Western musical traditions have actively sought to achieve with music: in so far as music has become High Art, for something to be music *is*, or has been for a long time, for it to have 'form.' Aspects of music's form are, e.g., rhythm and melody, but we can also describe it in terms of texture, depth, and movement. Listening to music, in this way, has become rather more like looking at a painting, where one is a spectator. Generations of composers, musicians and audiences have learned along these lines to keep the musical object clearly in mind, watching and following its movements (Carpenter, 1967, 59).

With this emphasis on musical form, music has for a long time been understood as a kind of enduring entity, as a "musical object" (Carpenter, 1967; Butterfield, 2002). And in this respect music and the visual arts have a long historical relationship (Maur, 1999). One famous example is that of Wassily Kandinsky who was convinced of the deeply intertwined workings of music and painting. He remembered hearing Wagner's *Lohengrin* for the first time, thinking how "Wagner had painted 'my hour' [sunset in Moscow] in music" (Ibid., 30). Kandinsky reflected by way of an analogy with a piano on how he himself in turn wanted to make music in painting: "color is the key, the eye is the hammer, the soul is the piano with its many strings" (Ibid., 30). Moreover, it is not uncommon to think that a musical object is not merely perceived *in* the music, but *is itself* the music, and accordingly, that we could, as it were, 'listen to an object.' A small example, decidedly humbler than that of Kandinsky, is that of Swiss architect Jan Henrik Hansen, who makes large sculptures of sounds or fragments of music. He presents these sculptures as *being* the music: "This [sculpture] is four seconds of a guitar string […], and this thing actually sounds like this [sound is played]."[16]

The musical object has deeply impacted traditional methods of musicology, in their approach to *musical pieces*; pieces, conceived essentially as works of *writing*, by which musical ideas have been encrypted in the score using the rules of meter, rhythm, harmony, counterpoint and so on. Live performance, on this view, is something altogether irrelevant to the art that music is, or at least secondary. As Arnold Schoenberg wrote: "[the performer is] totally unnecessary except as his interpretation makes the music understandable to an audience unfortunate enough not to be able to read it in print." Musical performances become nothing but the execution of a program, something that can be done well or poorly, but is nonetheless a mere "epiphenomenon of structure" (Cook, 2014, 87). The principle task of the musical performer, moreover, is to interpret the score, using appropriate sources, in order to arrive as close as possible to the original meaning which the composer had in mind. Understanding music, its meaning and ability to move, is thus a matter of studying the musical object in the score.

There is some discomfort in this understanding of music. As Patricia Capenter put it: "What kind of piece can be made out of so incorporeal a stuff as music?" (1967, 56) And moreover, how can there be some enduring musical object with predetermined properties when there is "no escaping the contingency and indeterminacy that inhere in every temporal act" (Hasty, 1997, viii)? Over the course of the the 20th century, there have been many movements in music that directly confronted these object-oriented views. And from the 1980s onward, musicologists and philosophers of music have also started to really turn the tables on the musical object. In both cases, the central objection can be summarized as follows: there exists no 'musical object,' be it the score or an idealized body, *outside time*; whatever music is or can be, it is always in a state of

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[16] TEDx Zurich 2012, quote at 05:13

becoming. And importantly, the kind of properties of form that we ascribe to music are not properties of the musical *object*, they are properties of the *activity* that music is.

We could start by looking at the idea that music resides in the score. An obvious objection is that not all music is written down: throughout history and around the world today, "the experience of live or recorded performance is a primary form of music's existence" (Cook, 2014, 1). The fervent Schoenbergian might reply that at least in principle all music *could* be written down. This might be the case, but the problem is not that music cannot be represented in a score, it is that scores "massively underdetermine their performance" (Butterfield, 2002, 331). Meaning does not lie embedded in the score, awaiting some objective extraction; it is created each time again in performance. When we speak, for example, of a musical piece like Beethoven's 9th symphony, it will be hard to say what its original meaning was – not the least because there is no extant original score. But more importantly, from Beethoven's own time up until today, the symphony's live performance will have been different every time, its meaning shaped by the intention and expectation of listeners and performers alike. Intentions and expectations are in turn passed on to subsequent performers, listeners, and social organization of music, by much more than only the score: life performances, recordings, schools of thought about what 'correct' ways of playing are, and cultural environments in which certain ways of playing become preferred over others. As a consequence, every interpretation of 'original' scores is necessarily anachronistic, because it can only envision possible meanings from within the present context. The 9th symphony as such is not something that fully exists in a score, it is "something existing in the relation between its notation and the field of its performance" (Butterfield, 2002, 331). Christopher Small thus suggested the term *musicking* for the *activity* that is music (Ibid, 329). What remains constant over time, as for example a particular 'style', is not some notational edifice, but the relatively stable constellation of relations which are recreated in every instance of playing or listening to music.

Rhythm provides a good case in point. "Central to our understanding of rhythm is the notion of regular repetition" (Hasty, 1997, 4). There are two distinct ways in which we commonly apply this notion of regular repetition, which Christopher Hasty distinguishes as *numerical* and *aesthetic rhythm*. Numerical rhythm is what we say when there is repetition which we consider to be measurable, such as the ticking of the clock or the seasonal cycles. Aesthetic rhythm is what we speak of in cases where there is no distinct periodicity, but where there is nonetheless a sense of movements and relations, such as with fluid hand gestures or the narrative of a story. In music theory, these two kinds of rhythm are distinguished as *meter* and *rhythm*, respectively.

Understood as properties of the musical object, meter and rhythm can be laid out in a score. Metrical 'time signatures' subdivide equidurational units of the score, the bars, into durations, so called up- and down-beats. A ¾ time signature specifies that one bar is divided into three beats. Rhythms are built into these metrical durations as subdivisions of a whole note, which is the duration of one entire 4/4 bar, making half, quarter, eighth notes, and so on, and are indicated using staff notation. Meter and rhythm indicate relative timing patterns. Absolute timing is determined in combination with *tempo*, the real time values given to metrical durations. Meter, rhythm, and tempo combined lay out a complete predictive description of the ideal onset times of every sounding beat in music.

In this way, meter is conceived of as an underlying measure of time, as a receptacle for the (constrained) free play of rhythm. Meter thus presupposes that musical time flows evenly throughout the piece; it lays out a kind of timeline on which future can turn into past along regular intervals, a strictly Newtonian view:

"Absolute, True, and Mathematical Time, of itself, and from its own nature flows equably without regard to anything external, and by another name is called Duration. […] The True, or equable progress, of Absolute time is liable to no change" (Newton, 1729/1968, 9, 11; quoted in Hasty, 1997, 10).

Because music theory has primarily focused on meter and rhythm in the score, the crucially active role of performers *and* listeners in the construction of rhythm has been much overlooked (Honing, 2013, 369). Namely, musical time does *not* flow evenly throughout performed music. In so far as music is *expressive*, i.e. does not sound 'mechanical,' or 'plain,' but rather with 'groove' or 'drive,' performers deviate continuously from the idealized onset times that meter, rhythm, and tempo together outline. Expressive performances vary their timing on many different levels, from the individual notes to increases or decreases in tempo over the course of several bars. Music *can* be metrically very strict, but certainly need not be, in order to be expressive. In any case, the metrical grid underlying the rhythmic structure of live performance is not static, fixed and predetermined at all, but is indeed very fluid. Moreover, the variations to rhythmic structure in live performance, are neither random nor simply reducible to a number of predetermined, general kinds of variation – *staccato* or *rubato* for example – but are intentionally and creatively introduced by performer(s). Interestingly, measuring metrical structure, or in other words the felt beat, in live music on the basis of sounding rhythm is very difficult, and often impossible (Honing, 2013, 370-1). Yet, listeners, regardless their proficiency in music or music theory, will typically have no problem identifying and 'connecting with' the metrical structure of music.

Meter, indeed, is actively *induced* by the listener, and involves at least the projection of expectations to the ongoing process of music's unfolding: "Meter is a perceptually emergent property of a musical sound, that is, an aspect of our engagement with the production and perception of tones in time" (London, 2014, 4). Justin London further suggests that meter induction is one and the same process as in cases when "we attend to the ticking of a clock, the footfalls of a colleague passing in the hallway, the gallop of a horse, or the dripping of a faucet [and] when we listen to a Bach adagio, tap our toes to a Mozart overture, or dance to Duke Ellington."

When it comes to live music, listening and performing are two sides to the same coin; not only does performing require that one can hear oneself and other musicians, listening in turn requires that one 'performs' the music. Often, we will find that the more we allow ourselves to 'synchronize' with the music, the more fine-grained and tangible the rhythmic form of the music becomes. The degree to which we are able to do this depends for a great deal on the cultural context within which we have learned to engage with whatever it is one calls music in the first place (Ibid., 159).

The 'object-ness' of music does not exist *prior to* the music or *outside* time, but it is actively created in performing and listening, and what is stable about the musical object is not 'its' structure but the act of listening; it is not the music that has rhythm, it is my particular mode of engaging with the music. This is also why we can say also of a painting that it has rhythm, because rhythm is in the performing and the perceiving; rhythm is an adverb not an adjective.

4.4 The musical organism

We can now bring these different strands together: programs and musical scores, machines and performances, things, substances and processes, metaphors and metaphysics. The question with which section 3 ended was whether the musical metaphor would be interesting to explore as a heuristic or theory-constitutive alternative to the program metaphor. My suggestion is that it would be, because it relies on an alternative conception of organisms, one that accords well with recent attempts to redress biological ontology. The musical metaphor accordingly emphasizes a different set of relevant questions, which too resonate with the kinds of questions and methodologies that systems biologists and evo-devo ask and develop.

Let me begin by pointing out in which sense machine metaphors rely on a substance metaphysical rendering of life, and, importantly, how they do not. I previously briefly outlined three different guises in which machine-talk appeared throughout the history of biology: *mechanicism, machine mechanisms*, and *causal mechanisms.* Only the first two of these make an ontological commitment. As Mary Hesse put it: “nature becomes more like a machine in the mechanical philosophy, and actual, concrete machines themselves are seen as if stripped down to their essential qualities of mass in motion” (1966, 163). In other words, the Cartesian machine of mass in motion emphasizes discrete entities with boundaries, which constitute discrete phenomena in coordinated fashion, i.e. through machine mechanisms. Today, the animal machine is essentially always complete in the form of the genome: the genetic program *contains* the adult organism. And even though many contemporary biologists will say that traits are constituted by both nature *and* nurture, this still upholds the sharp distinction between genes and environment, as well as an atomistic approach to ‘traits’ (Keller, 2010): it often results in such claims as that a certain trait is 71 percent genetically- and 29 percent environmentally determined (Polderman et al., 2015); i.e. that almost three-quarter of the organism *is in* the genome. The same is happening in the sequence-structure-function paradigm for protein function, taking proteins as things that do something by virtue of their properties. So, mechanicism in biology is committed to the existence of stable ‘things’ in the form of machine mechanisms.

Causal mechanisms, on the contrary, need not make this commitment. Causal mechanisms are a form of explanation, one which implies not the actual existence of a machine mechanism, but simply recognizes a particular mode of explaining a phenomenon to be effective (Nicholson, 2012). Population-level natural selection is such a causal mechanism. It explains variation in generational gene distribution in a step-by-step operative fashion, without the need for there to be the kind of part-whole constitution of a machine mechanism.

How is a musical metaphor different? I have argued in section 4.3 that music is best understood as a process, because music is always performative, which takes time, is creative, and can not be abstracted to a timeless instant or a representation that predetermines any particular performance. I should now show that this is also the understanding of music underlying the presently discussed metaphorical conception of development as a musical performance.

One way to see this is that the 'developmental performance' too emphasizes that the living system never exists 'outside of time,' outside the process of the organism's becoming. It rejects the preformationism and genetic determinism implied by genetic program-thinking. Instead, apparently stable entities such as scores or genes are presented as emergent properties, causal nexuses of the processes that *produce* notes or DNA and those that *use,* or interpret, them: "the 'gene' is a higher order structure than the DNA" (Gilbert and Bard, 2014, 130). And often a particular bit of sheet music need not even be causally implied, as when improvised music plays freely within the boundary conditions of a musical event; as the systems biologists like to have it: there is no privileged level of causation in living systems (Noble, 2006).

Music is not a passive bearer of qualities; whatever qualities, say of 'form', it has must be actively achieved and maintained by both performers and listeners. This continuous, active maintenance of wholeness is something that the machine metaphor does not account for; machines are static, they can at times *not* do anything:

> "an organism, unlike a machine, displays a *transitional structural identity*. The constituent materials of the system change, yet the organization of the whole remains. While a machine always consists of the same material components (unless and external agent interferes), an organism naturally maintains itself in a state of flux in which there is a permanent breaking down and replacement of its constituent materials" (Nicholson, 2013, 672).

This point has been made time and again through the notions of rhythm, harmony, and melody. They reconcile the inter*activity* of change and stability, or better, illustrate the active maintenance of organization. As Goethe reflected on the eighteenth-century saying that 'architecture is frozen music:' "The notes fade away, but the harmony endures. The dwellers in such a city move and have their being amongst eternal melodies; the spirit cannot sink, activity cannot slacken" (Tudor, 2011, 371).

Even more explicit is Karl Ernst von Baer's (1864) reflection on the harmonious interdependence of the processes that sustain the organism's organization:

> "We should, however, take the Life-process ('Lebensprocess') not as a result of organic construction, but as the result of a rhythm, or a melody, to which the organic body builds and transforms itself. Certainly, the organism must contain all means through which the individual Life-processes can express themselves. But those means themselves do not make up the Life-processes, they merely constitute its unity. In a piano, on which one has just now played a melody, must necessarily be present all the parts, through which one can bring about single tones. Nonetheless, it is not the piano that played the song we just heard; for the piano can bring many songs or musical thoughts into being.
>
> In the organism, however, the individual parts are themselves build in relation to en by the type and rhythm of one Life-process, such that they cannot serve any other Life-process. Therefore, I believe it is possible to compare the various Life-processes to musical thoughts or themes, and call them creative thoughts, which build their own bodies themselves. What we call, in music, harmony and melody, are here type (the composition of parts) and rhythm (the order of construction)" (von Baer, 1864, 281) [my translation].

Denis Noble again uses harmony in this sense, as a stable pattern of interaction between changing components of the system: "Their [multicellular life-forms] characteristic is what I will call cellular harmony: in a healthy organism they must co-operate in a harmonious way in the interest of the whole" (2006, 96); "Disturbing their harmony would have serious consequences. It was arrived after more than two billion years of experimentation" (Ibid., 97). So, the organism's musical form is an emergent upon activities, not a property of its parts. The musical organism is a process.

Further, what is stable in the machine metaphor is the thing and its properties, whereas in the musical case it is the sequences of events that are stable. Understanding an organism as the performance of a song means to equate it with the entire life cycle rather than merely the adult form. The life cycle is a stabilized pattern of change, from which thing-like forms are always abstractions. Evolution of organisms therefore becomes the evolution of life cycles: "evolution occurs by changing development" (Gilbert and Bard, 2014, 140).

Accordingly, questions about the music of development emphasize not merely the control by particular entities, or agents, but also the causal role of timing, intensity, and synchronization: the when, where, and how much of biological processes. For example, the DNA does not determine the performance's rhythm, the performance is itself rhythmic: "biologists now recognize that the development of phenotypic traits is guided not so much by the actual sequence of nucleotides as it is by patterns of gene expression" (Keller, 2010, 7). Explanations in the form of gene expression rate and concentration actually pervade today's literature when techniques are used such as gene expression profiling, micro-array-, and high-throughput screenings.[17]

Different musical or developmental processes are rhythmic in so far as different participants are able to 'synchronize,' an ability that does not depend entirely on intrinsic qualities but on learning, which happens over time and in an environment. In this way again, the musical metaphor invites an interest in questions of time and timing; aspects of development and evolution which evo-devo-ists have been trying to incorporate since many years. One example is heterochrony, the analysis of "the relative timing of developmental events, [and] change in the sequence of events" (Smith, 2001, 183). The term heterochrony has been around for a long time,[18] but the explicit recognition of timing as one aspect in which evolutionary- and developmental processes can be theoretically integrated is rather more recent:

> "Clearly, development is more than a sequence of stages [the 'normal plates' of embryology (see e.g. Hopwood, 2007)] or a simple accretion of new forms and functions. Understanding the timing of events and their relationship to one another can provide new insights into the elusive notion of emergent properties in development and can result in better descriptions of developmental events that do not depend on reductionist models. [..] Furthermore, we believe that reorganization occurs when a stable organization is disrupted by a component of a system changing at a rate that is different from others within the system. According to this view, slight differences in the relative timing of components can produce changes in a system" (Turkewitz and Devenny, 1993, 8-9).

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[17] Thanks to Jan Baedke for pointing this out to me.

[18] It was introduced in the late nineteenth century by Ernst Haeckel, as part of his theory that 'ontogeny recapitulates phylogeny' – the thesis that organisms, during their development, go through the various morphological forms of their species' evolutionary ancestors - and has undergone numerous conceptual transformations, most notably with Steven Jay Gould and Gavin de Beer (Smith, 2001, 169).

Such changes in the relative timing of developmental events have also been suggested to affect speciation (Minelli and Fusco, 2012). To this end, Minelli and Fusco have suggested that organisms, on top of a morphological- or behavioral phenotype, have a ‘temporal phenotype,’ such as temporal differences between life cycle events indifferent populations.

In sum, the musical organism relies on a processual ontology, in contrast to the animal machine, and thereby legitimately draws attention to interesting questions and approaches that move beyond the gene in studying and explaining the organism.

5 Conclusion

Is it useful to think about organisms in terms of musical performances? In this paper, I have given metaphors more attention than is common among philosophers and historians of biology, or biologists themselves. That is, I have taken seriously the idea that a conceptual metaphor can be of heuristic and theoretical importance to biology, rather than being merely a rhetorical tool for science popularization and education.

Metaphors are modes of reasoning in which we equate two conceptual domains in order to explore the one, the target domain, in terms of the other, the source domain. In using metaphors, we lay out analogies between both domains; highlighting those *positive* correspondences which we assume to be there, while downplaying those *negative* correspondences which we take to be irrelevant. Metaphors therefore always create only a partial view of whatever it is they help to capture. Yet, they are part and parcel of our efforts to make sense of abstract ideas. Their heuristic function lies not only in highlighting, drawing attention to certain aspects; we often use them to suggest that certain *neutral* analogies, correspondences of which we are not sure yet, could indeed be positive, thereby telling us something new about the target domain.

Two infamous metaphorical conceptions in biology are the program- and information metaphors for the genome. What programs, information, and genomes are taken to share are rational sequences of parts that are causally implicated in developmental events. The metaphor is used to suggest that these rational sequences are like a programmed code (positive analogy) that determines, controls or regulates the outcome of cellular processes (neutral analogy). Two relevant questions then clearly become how the code has been programmed (through evolution) and how it exerts control (through messenger intermediates). Metaphors, like these, thus often frame our understanding of abstract concepts, they introduce new terminology (the positive or neutral analogies) into scientific discourse, and they affect which questions or explanations we deem relevant or sufficient.

I have identified a particular metaphorical conception of organisms that in recent decades has come up repeatedly in discussions concerned with epigenetics, systems biology, evo-devo, and DST: ORGANISMS ARE MUSIC, and DEVELOPMENT IS A MUSICAL PERFORMANCE. The use of analogies from the domain of music is not new in the life sciences. The concept of 'rhythm' is one particularly striking example: towards the end of the eighteenth century, when the term started to gain currency among music theorists, rhythm was a central concept in the work of embryologists like Karl Ernst von Baer:

> "Rhythm may be a temporal structure, but unlike the continuous flux of time, it implies the restriction of the flux in favour of a rule. Indeed, it was this very feature that explained the power of rhythm around 1800: rhythm's ability to structure temporal processes. Rhythm did not suspend time, but subjugated it. It subjected to a rule the incessant change to which organic becoming was exposed." (Wellmann, 2015, 19)

The recent musical metaphors that I address here are explicitly proposed as alternatives to the 'machine metaphor' – ORGANISMS ARE MACHINES – which is found throughout the life sciences. Indeed, the mechanistic conception of life is part and parcel of the successes of modern molecular biology. Nonetheless, these musical metaphors take issue with it in two main ways. In the first place, they oppose the 'genetic program' view, which implies three problematic theses about organisms and development: *genetic animism* – the genome controls development –, *gene-centrism* – only knowledge of the genes matters for an understanding of development –, and *neo-preformationism* – the fertilized zygote already contains the entire program for development. In a second step, they voice a central concern with machine-talk: as much as the machine metaphor is a powerful *epistemic framework*, it should not become the *ontological framework* of biology. Because, in many respects, organisms are very fruitfully understood *as if they were* machines, but they *are not* machines.

Metaphors of musical performance try to present an alternative by using the notions of *score*, *performance*, *interpretation*, and *improvisation* as alternatives to code, program, execution, and control: while the genetic program determines development and the phenotype, the genetic score not only *under*determines development and phenotype, it is itself at the same time a product of development; while the genetic program dictates the execution of development, the developmental performance is a creative, constructive process in which causality can be found to occur in both directions.

On first inspection, it appears that musical metaphors are being used mostly as rhetorical devices, to illustrate, what can be called, an Organicist view: "an antireductionist systemic view of the organism emphasizing the complex interrelatedness of its developing parts" (Baedke, 2013, 757). At the same time, someone like Scott Gilbert is certainly aware of the heuristic and theoretical functions that metaphors can have in research. He studied with Donna Haraway, and wrote the foreword to a republication of her study on the metaphors and models in the Organicist biology of the Theoretical Biology Club, at 1930s Cambridge: "In *Crystals, Fabrics, and Fields,* biologists can access a set of robust biological narratives that subsume and enrich the one-dimensional genocentric story that has dominated biological discourse for the past quarter-century" (Scott Gilbert, in Haraway, 2004, xiv). But, in this study, I have looked only at published literature, not at lab-practice for example, and have only analyzed very explicit uses of musical metaphor, instead of trying to identify subtler influences. It may well be that in innumerable, inextricable ways musical thinking has already permeated the work of biologists like Gilbert, Noble and others.

Nonetheless, I suggest that these musical metaphors capture something which is of wider implication than the authors explicitly state. Understanding organisms as musical performances makes a different ontological commitment about organisms, and emphasizes their temporal, open-ended, and inextricably embedded nature. It turns around the mechanistic understanding of change and stability, of things and processes: while the animal machine is a static thing with parts that undergoes genome-controlled change, the musical organism is a temporal being that necessarily undergoes constant change and actively maintains the stability of the ways in which it changes; while the animal machine is the adult form, the musical organism is the entire life cycle; and while evolution of animal machines happens by changing the program that controls the formation of adult forms, evolution of the musical organism happens by changes in the relations between the processes that maintain the stability of musical form– the when, where, and how much of developmental events during the life cycle, at every level of organization.

Music is performative, and therefore deeply processual: it is not an object that exists *prior to* a musical event or *outside* time, but it is actively created in performing and listening. What is stable in music is not 'its' structure but the act of playing and listening. Similarly, living systems are processes, whose stability is actively maintained over different timescales – metabolic, developmental, and evolutionary. Musical thinking can inspire productive investigations of biology's central target phenomenon, the organism, and can help to move beyond the narrative of genes and machines.

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