Variations on the theme of invariants: conceptual and mathematical dualities in physics vs biology[1]

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1. Through the looking glass: could physics and biology reflect each other?

When one tries to elaborate a mathematical theory apt to explain some aspects of biology, though starting from the clue of one and unique materiality, anyhow one becomes aware of some peculiarities. Especially during the elaboration of *theoretical extensions* of physics by new observables (Bailly and Longo, 2008, 2009), which gives an account in (possibly new) mathematical terms of *living beings' singularity,* some characteristic polarizations have been enlightened and verified. A key aspect of this approach is the claim of a duality: a conceptual opposition between some theoretical aspects of the two disciplines. *Table 1* synthetically shows a representation of some conceptual dualities or, could we say borrowing the term from biology, a *crossing over* between physical and biological theories. For example, in our approach, biological time and its irreversibility are viewed as constitutive operators of biological complexity while energy is analyzed as a parameter, in contrast to the understanding of time as a parameter and energy as an operator in (quantum) physics (Bailly and Longo, 2009). As a matter of fact, energy appears as a parameter in allometric (scaling) laws, in biology (Savage *et. al*, 2004). Moreover, as a conceptual symmetry to entropy, we also proposed, in the same paper, the notion of anti-entropy as a (measurable) local reversal of (physical) entropy production corresponding to increasing biological

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[1] **Human Evolution**, vol. 25, n. 3-4, pp. 167-172, 2010.

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organization, both in Evolution and embryogenesis.

Another properly biological extension of physical analysis of time, our two dimensional approach to time includes a physical (thermodynamical) time *plus* a second dimension, which accommodates proper biological rhythms (Bailly *et al.,* 2010).

Let's add that the theoretical notion of *conceptual opposition* is sharply distinguished from a metaphorical framework (Longo and Frezza, 2010), which is so common in biology. The strength of this methodological insight lies in a cross-logical procedure that clearly shows the *reversal* of parameters and relevant observables between physical theorization and biological theory building. Let's remark that in differentiating the theoretical frames of physics and biology we do not intend to make a material or *ontological* leap, but to underline a *methodological* difference between the two theoretical approaches. We are deeply convinced, it is our metaphysical assumption, that living beings are just bunches of molecules. The point is *which kind of theory* may help us to better understand and explain these physically "singular" bunches of molecules. Then, unification with existing or novel physical frames could possibly follow. See the current work in Quantum/Relativistic unification, by inventing radically new theories encompassing both current frames. Moreover, and in contrast to the incompatibility of the Quantum Field w.r. to the Relativistic Field, our proposals for biology are based on *compatible extensions* of some *specific* physical theories. Of course, here our attempt is purely phenomenal and the absence of any reference to underpinning elementary physico-chemical processes corresponds to the historical practice of physics. In fact this discipline has been able to describe, in a very effective manner, Galilean inertia and the falling of bodies without any reference whatsoever to Democritus' atoms of which these bodies were composed even back in Galileo's time. Later, Einstein unified inertia and gravitation, but still disregarding quanta, since, as of now, the gravitational (relativistic) and quantum fields are not yet unified, as we recalled. This kind of theory building made at different phenomenal levels has been a crucial part of the history of physics. The *unification* (Quantum/Relativistic) goes on by bringing two well constructed theories in relation under a novel perspective.

This diagram gives a synthetic representation of some conceptual dualities that have been individually discussed in detail (Bailly and Longo, 2008; 2009; 2010; Longo and Montévil, 2011):

PHYSICS	**BIOLOGY**
specific trajectories (geodetics) and **generic objects**	**generic trajectories** (possible/compatible with ecosystem) and **specific objects**
point-wise criticality	**extended criticality**
(Schrödinger) **energy** is an **operator** (Hf), **time is a parameter $f(t,x)$**	**energy** is a **parameter** (allometry), **time** is an **operator** (measured by entropy and anti-entropy production)
reversible time (or irreversible for degradation-simplified thermodynamics)	**double irreversibility of time** (thermodynamics and phenotypic complexity constitution)
randomness is **non deterministic** or deterministic non predictability **within a pre-given space phase**	**randomness** is **intrinsic indetermination** made by changing phase space (ontogenesis and phylogenesis)

Table 1. A possible theoretical differentiation between inert and living matter is described through conceptual dualities.

2. Specific and generic: objects and trajectories

Let's start with a simple remark. In physics *objects* are *generic*: they are invariants for experiments and theory (for instance, a Galilean weight or an electron as solution to Dirac's equation is equivalent to any other, it is generic); while *trajectories* are *specific*, as they are geodesics, an optimal path in the intended phase space. This is physics, from Newtonian mechanics to Schrödinger equation[2]. Antithetically to physics, in biology the *objects* (rather than trajectories), should be described as *specific* (rather than generic). This is due to the individual variability of living beings and their specific history, the analysis of which doesn't allow generalizations like in physics standard procedures. On the other hand, in biology: *trajectories*, phylogenetic, ontogenetic, or even those of actions, are *generic*; they are co-possible ones, i.e. they are the result of paths compatible with the co-constituted ecosystem and they do not follow optimality criteria. This is, for instance, one of the reasons for the explosion of the number of species, whom Darwinian natural selection theory refers to: trajectories are *explorations of compatible paths*. As a matter of fact, without genericity of routes there would be no Darwinian evolution (as life growth or explosion and, then, selection of the incompatible) and therefore no phylogenesis nor ontogenesis.

If one looks at Darwinian Evolution, the paths followed by phylogenesis are possible (or generic) ones, yet subjects to structural and phyletic "inertia" such as architectural and phyletic constraints (Gould and Lewontin, 1979). Ontogenesis goes along generic paths as well, the co-possible ones, yet with respect to more restrictive constraints, that are developmental, which are a subcategory of phyletic constraints. For example, in mammals, evidently the mother's womb canalizes embryogenesis "more restrictively" than an ecosystem may canalize the evolution of a species. There is a superposition and an entanglement of

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[2] Geodetics are obtained as sums or integrals of gradients, sometimes highly complex ones, but always as "critical" paths, that is maxima or minima. Mathematically, they extremize a functional in some phase space (this is Lagrange vs Hamilton approach). Even in Quantum Mechanics a quanton will do the same not in an ordinary space-time but in a possibly infinite dimensional Hilbert space: Schrödinger equation is derivable from the Hamiltonian and determines a quanton's evolution as the dynamics of a probability law.

constraints as Gould and Lewontin have clearly enlightened in their distinction of architectural, phyletic and developmental constraints (Gagliasso, 2009). In the lines of Evo-Devo theories, we can add that both phylogenesis and ontogenesis are forms of differently canalized variability. In fact, the core question of evolutionary developmental biology is *evolvability*, that explains how variation is generated through evolution and takes into account the pluralistic feature of organisms' developmental causes. "Development matters to evolutionary explanations because it structures the way in which variation is presented to natural selection" (Hendrikse *et al*., 2007, p. 400).

If we move again along physics we find exactly the opposite situation: *generic trajectories*, whether they exist (for example Feynman path's integral) are only rare exceptions, under determined constructions. And anyway, whenever the object would be put in the possibility to reiterate the path, it would statistically test every possibility. That's why an analysis of physical trajectories through criteria based on "selection" does not contribute to physical intelligibility: physical theories are much stronger, as they propose extrema of functionals (by energy conservation principles, say, or geodetics).

In order to summarize and conclude, let's go back to the first part of *Table 1* and look at it with this crossed standpoint: we notice a sort of double crosswise relation, as a chiasm.

PHYSICS	**BIOLOGY**
specific *trajectories* **-------->** (geodetics) **generic *objects*** **-------->**	**generic *trajectories*** (possible/compatible with ecosystem) **specific *objects***
***specific* trajectories** **-------->** (geodetics) ***generic* objects** **-------->**	***specific* objects** ***generic* trajectories** (possible/compatible with ecosystem)

Table 2. Trajectories and objects stand to specificity and genericity in a "crossed inverse proportionality" regarding biology vs physics.

3. Laws and dynamics

It is nevertheless useful to insist on the idea that every theoretical-mathematical structuring is a human construction: science is a construction of objectivity (as spelled out at length in Bailly and Longo, 2010). There is always a friction of the physical-biological world with the cognitive practices and representations which lead to a theory. We may now reverse our perspective, in a Kantian way: our representation of the crossed relation of the physical versus the biological world is not properly the way matter is (thing in itself). Rather it is our method to norm and rule the matter proper to these different domains, inert and living matter, its *phenomenality*. As we said in section 1 it is not an *ontological*, but a *methodological* question. But starting from this methodological frame we may now move a step in the direction of matter.

We propose now to look not at objects and paths, but at their relation, or interaction. We gain immediately a dynamics, a process. In fact, in section 2 we have fixed as principal references trajectories and objects in physics and biology and we have evaluated their correlation with specificity and genericity. Then we have considered as main elements specificity and genericity in the crossing over between physical versus biological objects and trajectories. If now we look at the *correlation* of the *object* with its *route*, we become aware that *in physics* they are described as *independent* the one from the other. A trajectory is defined independently from the different objects that pursue it and it is given by the physical law. This allows having *generic objects* with *specific trajectories*, that is our correspondence above. *In biology* is exactly this kind of correlation or law which is *not possible*: living beings are *never independent* from their paths. Each organism is the result of its own route and history.

With this crossing over one becomes aware in a very immediate way of different physical vs biological principles. They operate in the one and only materiality, which is differently organized and offers two different phenomenalities:

- what is exactly the *fundamental principle* in the case of physics, the genericity of the object and thus the universality of the law, is *opposite* to the *primary criterion* in biology, the specificity of the individual;
- what is *not relevant* or without meaning in physics, as errors or history, becomes a *core principle* in biology, as we will see in sections 4 and 5 more in detail. We can argue that if one wants to express into physical terms the correlation between the object and the trajectory, the physical law is not straightforward suitable for biological domain;
- what is a *correlation* in physics becomes more properly an *interaction* in biology, where variability is one of the principal actor in all processes.

In general a law for objects and trajectories of one domain would not suite the other, but this fact, at least, can be expressed by an opposition, as we are proposing. We claim that these conceptual oppositions may contribute to theory building in biology better than flat theoretical transfers. At the core of the theoretical proposals in the quoted Bailly-Longo's book and papers stands this chiasm between physics and biology as a methodological assumption. It is an epistemological attitude which may help avoiding a surreptitious determinism as well as teleological imposition from above that describes every objects as "made for" or "function of".

4. Exploring possibilities

At this point we can try to put all we have described till now in a more comprehensive frame. Two key features of living being's paths can be resumed in dependency on history and on the traces of history as biological "memory". The historical-evolutionary and ontogenetic course codetermines the process of individualization of each living being, species... From this standpoint we can underline also how the role played by error and pathologies clearly separates a possible theory of living phenomena from any physical theory, where these two notions make no sense. In fact in physics trajectories never include errors, as they follow optimality (see next section). Genericity of trajectories, on the contrary, allows including pathologies in the analysis of living phenomena: pathology may be at the origin of new possible evolutionary paths. Similarly even an "error" within the process of learning, via *retention* (or memory), can precede a successful action, via *protention* (or anticipation) and so on. These notions, that are not proper to theories of the inert, based on specific and optimal trajectories, must be present in any theory of living phenomena, in particular when attempting to mathematize them. Their unification with the underpinnings molecular processes is a subsequent step: we stress that in order to "unify" is necessary to have at least two theories of different phenomenal levels to be unified.

We can briefly resume that the core of living matter dynamics, at all levels, from evolution to human action, is *exploring possibilities*; something that doesn't make sense in physics and that contributes to the difficulty in explaining physically living beings.

We want to enlighten this passage, because it gives a good general appreciation of living phenomena.

We can describe living process as:

- *active* (protension)
- *responding* (to the environment and natural selection)
- but not *determined completely by a pre-given* set of known physical laws, since variability and evolvability exclude such a complete determination, as we are trying to show through the conceptual dualities hinted above (which suggest a biological form of extended "determination").

5. Right and wrong: errors and optimality

> *So far we have incorporated only our* errors
> *and all of our consciousness refers to errors!*
> Frederich Nietzsche

For better clarifying this central idea of living processes as exploring possibilities, and its consequences, we can stop for a moment on one consideration: “A physical object never goes wrong”, a falling stone or a river never takes the wrong path. By following local gradients, thus by the sum of local optimizations (a path integral, mathematically), a stone or a river always chooses the best path, a geodetics. From this very same standpoint, instead: “Living objects go wrong most of the time”. A paramecium for instance does not follow exactly a gradient, in particular not in its preferred ecosystem, like a much polluted liquid solution; but it has a weak form of retention that allows a protensive attitude, as it can go the wrong way and thus learn. With *protensive* we mean a very basal attitude, proper of living beings, to act, interact and react, based on memory and along an expectation, as a primitive form of cognition. This allows enlightening a proper “biological inertia”, which is part of the peculiar dynamics of organisms’ actions and rarely a perfect geodetics (Longo and Montévil, 2011). Similarly, from an observer standpoint, evolutionary and embryogenetic paths are mostly wrong (most species are extinct and embryogenesis fails in a large percentage of the times).

This metaphor allows to appreciate at the level of the outside observer the “question of error” that differentiates living organisms’ from inert objects’ paths. Let’s make explicit the use made of *optimum* and *wrong* when we said that: “A physical object never goes wrong while a living object goes wrong most of the time”. We took into account the perspective of physics and especially in the case in which *optimum* refers to a *geodetics*. Now, physics is not moral neither teleological, nor our approach would be teleological or moralistic, as we want to enlighten biological specificity in an enlarged, but physical and non-teleological perspective. In *physics* what goes right goes right and *it doesn't make sense something that goes wrong* as we have discussed above. But in *biology everything goes right or wrong only and always from a particular standpoint* and *with a crossing of viewpoints* (Berthoz and Petit, 2006). Only under the illusion of a disentangled observer, nothing goes right and nothing goes wrong, as it happens in physics where the universal laws reflect exactly this fact. On the contrary, in every position that is *situated*, *incorporated*, *contingent* and *autonomous*, which means necessarily in a determined space and time (even the standpoint of the fictional observer), there is a specific-individualistic viewpoint coming out. For instance, in an aggression of an organism by a virus the positions that emerge are radically opposed: what is right for one is wrong for the other.

Remembering Varela's closure thesis (1979), let's say that all possible variability of a living organism is organized, closed and immanent to the individual itself. "*Omnia mea mecum porto*", as the Stoic precept says; that we could translate here as "Everything I need is with me", which specifically claims the organizational autonomy referring to the organization and completeness that make the individual *being itself*. The individual doesn't receive from "abroad" its autonomy: it *is* this autonomy. Let's specify that as every process also individualization is contingent and is led through the co-constituted interaction of the organism with the environment and through its history as we hinted above.

We can cross-refer to what said in previous sections. The contingency and the independence, which contributes to the specificity of the individual, moves along a generic, non specific path. This generic path gains its determination contingently, through individual's life: it becomes a specific point of view with a specific memory only through actions, selection and evolution (both in ontogenesis and phylogenesis). In fact the intelligibility provided by Darwin's Evolution is not a predictive, but an historical one and it is largely based on failures. On the contrary the inert object moves along specific and, in principle, predictable (or at least determined) trajectories, optimal ones for every different object and by this it is an invariant of the dynamics (relatively to the reference system) as we will see in detail in the conclusion. We found pedagogically useful introducing this simple metaphorical opposition between the precise notion of *optimality* (geodetics) in physics and antithetically a concept such *going wrong* in biology*,* which makes sense, whenever it makes sense, only in reference to errors, to history and to a specific point of view.

6. Biological unstable stability: extended critical situation

This crossing-over between physics and biology enlightens a conceptual line focusing on eccentricity and instability. The major components of this instability sketched till now are: constant variability, divergence from physical optimal paths and "errors" in general experience of exploring possibilities. All these are declinations of this permanent instability, in a sort of Epicurus' παρένκλισις or in Lucretius' translation a *clinamen* (Lucretius, *De Rerum Natura*, II, 216-224 and 284-293). The eccentricity of the theoretical notion of living beings in comparison to physical dynamics could be seen as a sort of *shift* from the centrality of mathematical invariance, so relevant in physics, towards structural stability and variability. Along these lines, it is possible to illustrate a comprehensive picture of some of the features that express and impress a *physical singularity* upon living organisms.

First of all, to understand the quavering "living state" of matter (Buiatti, 2000) and its processes one may introduce the concept of *extended critical situation* (Bailly and Longo, 2008). This concept comes along the lines of existing theoretical approaches in biology. In fact, we know from physics, in particular from the studies of the 1970s (Nicolis and Prigogine, 1977) that the analyses of self-organised systems far from equilibrium are relevant for a physical understanding of organisms. The physical study of critical states has enabled to highlight the presence of further examples of self-organization (Bak *et al.,* 1988). Thus providing the inspiration for a whole stream of studies that can be summarized in the idea of *self-organized critical state* emerging from chaos, or "order for free" (Kauffman, 1993) and the various theories on the *emergence* of complex structures from basic underpinnings elements (McLaughlin, 1992).

The concept of *extended criticality* proposes a conceptual and, then, a mathematical extension of these theories. The point of departure is that during phase transitions a number of characteristics occurs that show the shift from *local* to *global* – divergence of the correlation length for which infinitesimal variations create finite modifications, the appearance of order ... – in which the global structure is completely involved in the behavior of the various elements (local structure). Again by a crossing-over, extended criticality opposes to the notion of criticality in physics, as critical transitions are mathematically defined for *point-wise* values of the control parameters. In the case of living beings, instead, the threshold of criticality is *extended* in time and is represented by a non-null volume in the space of all relevant parameters. Without entering in the discussion (Bailly and Longo, 2008; 2010), we can say that intuitively this is due to the capacity for adaptability and plasticity of living beings, which resists to variations (within broad limits) of the parameters (time, temperature, pressure...), while being in a permanent "state or phase transition". In other words the living state of matter may be resistant to modifications of the parameters, yet it is always in a *critical situation* in relation to its extended, but *limited* existence. Living objects are always on a threshold that changes dynamically: their entire structure of correlations (coherence structure) is transient between one phase and another, within the limits of a structural stability in relation to its ecosystem (Bailly and Longo, 2008; 2010).

A mathematical approach to extended critical transitions is being developed by our group. Scale dependence and scale invariants are at the core of it. Subject to scale shifts, the focus of the analysis must be rearranged continually. We hinted here an expressive frame for this *eccentric translation* from physics towards biology, which tries to take into account also a translation of concepts. We believe that making reference to conceptual dualities is a way to give preliminary but "fundamental" level of intelligibility to the correlations of physics vs biology.

7. Adopting double standards: mathematical invariants and variables vs biological variability

Mathematical invariants are given by transformations that preserve them. Suitable categories of objects must be given jointly to their invariant properties, which are preserved through transformation (morphisms, functors). Such properties may be relative to measure, topological, algebraic… structures. In this frame:

1. *Objects are domains of variation for* the intended mathematical variables. For example, suppose that a variable x is meant to vary on a topological space, D, say, where a continuous function h acts, with co-domain or range E. Thus, $h(x)$ is in E and h gives a "law", which is uniform in x (it *uniformly applies* to all x's in D). In physics the application is straightforward. Typically, Newton's law $f = gm$ applies *to all* physical bodies (*the intended domain*) and gives force or weight as a function of mass x, a property of a physical body: $f = h(x) = gx$, where g is the gravitational acceleration.
2. In general, in a *physical law* any structuring of the intended domain, the distance or differences of mass, say, a metric, is transformed *uniformly* and effectively by law as a mathematical function.

3. The situation may be more complex: “We have to solve equations”, says Newton. In fact, equations provide the invariants that we may call “objective determinations”: if they are invariant (stable), for example by symmetry translations in time, then energy conservation derives as objective determination from this very invariant (this is Noether’s theorem, see (Bailly and Longo, 2010)).

Variables in the equations are thus *uniformly* handled as *ranging in the intended domain of variation*, hence they are *invariant*, uniformly transformed by a function, possibly a solution of the equation, *if any*. In classical dynamics, this solution usually yields the function h above as a specific trajectory (optimal). We can correlate these two facts:

- *genericity*: generic objects are in the domain of variation *for* the intended mathematical variables (1);
- *uniformity and determination*: there is a *uniform* application of mathematical function to all physical bodies (the intended domain) (2 and 3), every structuring of the intended domain is uniformly transformed by a mathematical function.

Now we can make a comparison with biology. Though it is *conceptually* heuristic and interesting to talk about a *domain of variation* referring to a living being, we need to underline some fundamental differences. First of all a living being *would be itself* that specific domain of potential variations, and not *in reference to* generic variables, as it happens for the objects of uniform variations. In fact, regarding the organism, as we have seen in relation to its autonomy and contingency, its peculiar domain of variation is autonomous in itself (closure) and doesn’t refer in a pre-determinable way to anything else. Any variation is intrinsic (internal to the individual, yet in relation to the external environment) and correlated to unpredictable variability. There is no way to move aside or remove this entangled link between intrinsic variability, unpredictability of trajectories and unstable structural stability in biology. And the problem further increases when we move towards complex entities, such as humans, where our epistemological look becomes more and more demanding.

Nonetheless, there exist infinitely many and very relevant applications of this general physical-mathematical method in biology. In fact they concern many *properly* physical aspects of life and they are so well-known and successful that everybody acknowledges their interest. We find more interesting to see, instead, *when*, *how* and possibly *why* this approach *could go wrong*, to use the expression mentioned above.

Suppose considering that the DNA is a mathematical invariant ranging on the domain of macromolecules. Then, one may refer to the genotype as a mathematical variable, to be transformed uniformly into a … phenotype, say, which, if we translate into what said before, would be the set of properties of an organism given by a function h. This function h would provide a uniform law that gives the entire phenotype $h(x)$ for all macromolecules that have that DNA structure, x. This mathematically means that h is a function of x, but its definition must be *independent of* x as it applies uniformly and generally to *all* x's in the intended domain. The law h would be Schrödinger's "architect" contained in the chromosomes themselves, as code-script (at once a program and an operating system in modern terminology).

8. Conclusion

It can be easily grasped from what we said till now, how false it is defining embryogenesis as a *uniform function of DNA* (the invariant above) *independently of the interactions of DNA* with proteome, the cell and the global epigenetic context – including the whole organism which is being formed; and concerning heredity and development in the case of humans even the symbolic context is not negligible, as Jablonka and Lamb has recalled (Jablonka and Lamb, 2005). And it is not a matter of claiming that a living phenomenon "is more complicated" than the analysis of a falling body: it is conceptually different, as it requires theoretical extension of current theories of inert, as we said in the beginning and proposed in several papers. We need to invent or "distill" a different family of concepts, which may capture the eccentric physical instability of organisms, as we have tried to underline above by several notions based on dualities and by extended criticality, typically. In fact, for no uniform effective transformation DNA can be analyzed as an invariant of the context and also: how many contexts and interactions should we consider? Nor the context is just "noise", to be regarded as *ceteris paribus* (Rosemberg, 2001). In fact, the result of all these destabilizing processes is nonetheless an *individual*, depending on historicity and on a contingent formation; so it would need *specific* and not *generic* notions, as both x and $h(x)$ are in a physical analysis. In biology, as we have hinted, it is the *path* (the embryogenesis or the evolutionary path) which is *generic*, though in different degrees. For example in evolution, possible paths are taken by speciation, selected by incompatibility, *never by optimality*. This stands again in the opposition of optimum and wrong. The more complex the result of evolution is, in Gould's sense (and not in a teleological meaning, Gould, 1996) the larger are the differences in individuals' ontogenetic specification and their variability. This biological variability of the "end result" of ontogeny may be even contra-variant w.r. to the variability of the DNA: humans have much less variability in DNA than other primates, say. Yet, this is compensated, as adaptation process, by human very plastic brain and cultural variability.

Conceptually and theoretically wrong frames, such as the one gene one protein theory and the Central Dogma, dominated in large and consistent areas of biology for nearly half of last century. It determined an “epistemological culture” in Fox Keller words (Fox Keller, 2002). From that theory, going back to the example above, one could possibly define a uniform and effective function *h* (even in the restricted sense of computable, or programmable) going from DNA, *x*, to proteins, actually to phenotype (or even to behavior, as claimed by many). Besides biological inadequacy of this mathematical approach that we tried to enlighten, observe that the belief that there could be a linear process unidirectionally going through a context, like the cytoplasm of an eukaryotic cell, is even physically absurd. As a matter of fact, this theoretic frame was established by looking at specific cases in bacteria, where, exceptionally, they might apply, as presumably to other very few peculiar examples. But the quasi-turbulent frame of an eukaryote’s cytoplasm, with quasi-chaotic enthalpic oscillations of macromolecules and largely statistical stereo-specific interactions, is a physically implausible frame for such a predictable (programmable) determination (programming is a form of “predictable determinism”).

> Too often, the adaptationist programme gave us an evolutionary biology of parts and genes, but not of organisms. It assumed that all transitions could occur step by step and underrated the importance of integrated developmental blocks and pervasive constraints of history and architecture. A pluralistic view could put organisms, with all their recalcitrant yet intelligible complexity, back into evolutionary theory (Gould and Lewontin, 1979, p. 598).

In conclusion, biological diversity is the result of a possible, contingent, evolutionary and ontogenetic path mostly failing and for this leading to an individuation. *Variability* must not be confused with the mathematical notion of *variable*, which beautifully applies to the *genericity* of physical objects and, by functions describing (classical) dynamics, provides the specific trajectories of each physical object. Though a word resemblance, the meaning and the domains of application are and should stay, as we hope to have thrown some light on, very different. Yet, correlated by conceptual dualities, which are a relevant form of correlation, in this case, between physics and biology.

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(Longo's papers may be downloaded from http://www.di.ens.fr/users/longo/)

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