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SPECIAL ISSUE ARTICLE

Guiding Principles and Special Laws[†]

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Abstract

We analyse the structuralist notion of a *guiding principle* in empirical science in order to show its fruitfulness to tackle some central issues belonging both to the general as well as to the special philosophy of science, while also providing some clues to understand recent developments in the philosophy of science. We shall conclude by laying out the core characteristics of guiding principles.

KEYWORDS

guiding principles, special laws, structuralism

1 | GUIDING PRINCIPLES VERSUS SPECIAL LAWS: THE CASE OF CLASSICAL MECHANICS

Having briefly introduced the notion of a *symbolic generalisation* for the first time in the 1969 *Postscript* to *The Structure of Scientific Revolutions*, Thomas Kuhn discussed a specific kind of symbolic generalisations in *Second Thoughts on Paradigms*, which he labels schematic forms or generalisation sketches, and characterises thus:

> "generalisations [like $f=ma$…] are not so much generalisations as generalisation-sketches, *schematic forms whose detailed symbolic expression varies from one application to the next*. For the problem of free fall, $f=ma$ becomes $mg=md^2s/dt^2$. For the simple pendulum, it becomes $mg\ sina=-\ md^2s/dt^2$. For coupled harmonic oscillators it becomes two equations, the first of which may be written $m_1d^2s_1/dt^2 + k_1s_1 = k_2(d+s_2-s_1)$. More interesting mechanical problems, for example the motion of a gyroscope, would display still greater disparity between $f=ma$ and the actual symbolic generalisation to which logic and mathematics are applied." (Kuhn, 1974, 465, our emphasis; see also 1970 Postscript)

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The (metatheoretical) structuralist notion of a *guiding principle* and its accompanying notions of *specialisation*, *special laws*, *theory-net*, which were first introduced by the end of the 1970s and beginning of the 1980s,[1] may be regarded as a further elaboration and formal explication of the Kuhnian notion of schematic generalisations.[2] The basic idea is that in complex and well-developed scientific theories not all laws are on the same level, that is, not all have the same significance and scope. In such theories, laws appear in a hierarchical structure: There are laws of a very general nature that apply to all phenomena studied by the theory in question, whereas other laws are more specific and have a restricted range of application. The whole set of the theory's laws thereby constitutes a hierarchical net-like structure with different branches according to the different sorts of phenomena being investigated. In the paradigmatic case of classical particle mechanics (CPM), the theory-net may be represented by the following graph (this graph represents only a simplified portion of the net; for a more precise and complete version, see Balzer et al., 1987, ch. III.3; Figure 1).

On the top of this theory-net we find Newton's second law, that schematic principle of mechanics to which Kuhn refers, and which takes successively specific forms for different specific applications. This fundamental law of CPM is the theory's guiding principle: We may interpret it as a heuristic guide for research within the theory. Let us call it *GP-CPM* (for "guiding principle for classical particle mechanics"). A succinct formulation of its guiding nature might run as follows:

> *GP-CPM*: *Given any path of an object that might be considered as a candidate to be explained within CPM (i.e., a path that might be considered as an effect of a mechanical action), there are some forces such that their vector sum becomes equal to the product of the object's mass times its acceleration.* More formally: *For any particle p at time t, there are functions f_i such that*: $\sum_i f_i(p,t) = m(p)\cdot \mathrm{d}^2 s(p,t)/\mathrm{d}t^{2\cdot}$.

Consequently, when confronted with the paths of different phenomena (e.g., the motion of a spring, or of a pendulum, or of a planet), research in CPM consists in looking for special sorts of forces that are responsible for those paths (e.g., elastic forces, percussions, gravity) or for a combination of several sorts of forces. In this way, the guiding principle will be specified successively until it takes, as Kuhn says, different forms for different kinds of applications. It is important to note that the relationship between the net's upper-level and lower-level laws is not of a deductive kind: The lower-level laws are not deducible from the upper-level ones, nor vice versa. The relationship is rather one of *specialisation* or specification: The lower-level laws are specialisations of the upper-level ones; they specify for each case being investigated, which are the concrete parameters that the schematic law(s) leaves unspecified.

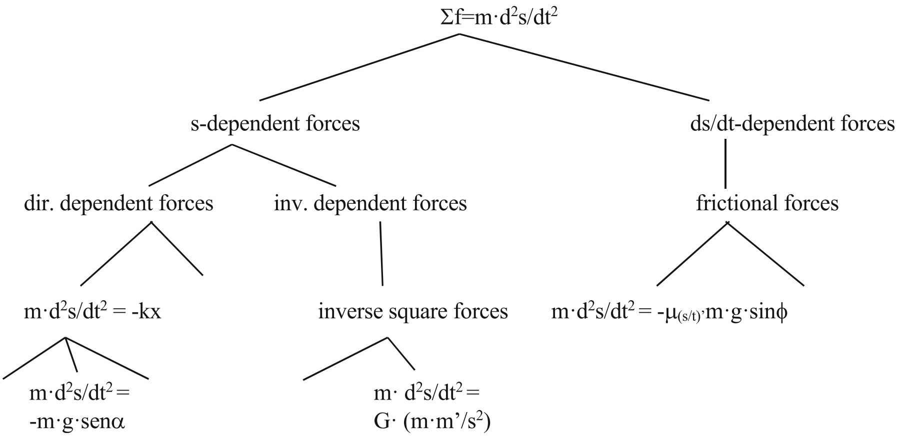

FIGURE 1 Theory net of Classical particle Mechanics

CPM's guiding principle is a heuristic principle in the sense that it settles the conceptual and methodological frame that the mechanical explanations of particular trajectories have to fit in with. To put it in a different way: To consider the path of a particle as a mechanical phenomenon just means to be ready to look for the corresponding mechanical forces that fit in with GP-CPM. This endeavour may be successful, or it may be not. It was paradigmatically successful in the case of the path of the Earth and other planets around the Sun; for a while, it was not successful when considering Uranus's path around the Sun – until Neptune was discovered; and it was never successful with respect to Mercury's path, of which we know it was an outstanding anomaly for CPM that would ultimately be explained away only by general relativity. CPM's guiding principle was neither completely successful with respect to optical phenomena, contrary to the hopes of Newton himself and his immediate followers: Certainly, some optical phenomena like reflection and refraction could somehow be fitted into CPM's framework, but others (like diffraction) would prove to be stubbornly recalcitrant to a mechanical explanation so that ultimately all phenomena related to light would become expelled from CPM's range of applications.

It is important to notice the difference between the last case of unsuccessful application of CPM and the Mercury example. The failure to treat some optical phenomena within CPM's framework led physicists in the long run to discard the assumption that light is a mechanical phenomenon; however, this was not seen as a failure of CPM's theoretical machinery but rather as the discovery that something that was thought as mechanical phenomenon was actually not; thus, the theory's empirical scope was somewhat narrower than it had first been thought. On the other hand, the problem of Mercury's orbit for CPM was of a very different nature: Nobody envisaged to throw Mercury's orbit out of the range of CPM's applications, and the reason was that this case was too similar to the other cases of paradigmatic successful applications of the theory (the other planets' orbits) as to be dismissed as a case foreign to the intended range of applications of the theory.

This difference in the treatment of light and Mercury "anomalies" within CPM is related to another of Kuhn's intuitions: the relation of "family resemblance" between different applications of a theory, as well as the status of being "paradigmatic" for some of them. For instance, planets (including Mercury) are paradigmatic cases for the application of CPM. It would have been "pragmatically inconsistent" to throw Mercury out of the range of intended applications while maintaining the rest of the planets because all planets share the family resemblance that makes them going in or out together. Given the paradigmatic character of many of the planets, CPM cannot simply dispense them. On the other hand, different light phenomena (reflection, refraction, diffraction, …) are linked in respects that make it impossible to consider some (reflection, refraction) as mechanical phenomena and some (diffraction) as non-mechanical; therefore, all must go or stay in CPM together. However, none were CPM-paradigmatic, they could all be expelled from CPM's intended applications.

It is worth emphasising that, although the range of paradigmatic applications of a given theory remains historically quite constant (and that is why the Mercury case was so disturbing for CPM practitioners), the range of successful applications on the whole may increase in the course of time; however, this will not normally be seen as a dramatic development: A hundred years after the publication of Newton's *Principia* 1687, Coulomb managed successfully to include the phenomena of electrostatics and magnetostatics (which had previously been considered as non-mechanical) within CPM's frame. Newtonian physicists were certainly happy about this, but nobody regarded it as a dramatic or "revolutionary" change.

Our remarks so far are related to one of the most interesting, although also most intriguing, features of guiding principles – their being "empirically unrestricted." Because guiding principles are just suggestions for the kind of parameters to be specified by the special laws when considered on their own, taken in isolation they scarcely tell anything about empirical reality. As isolated propositions, they cannot really conflict with reality. The conflict may come out only when they are combined with special laws, more precisely, *through their specialisations*. This feature of guiding principles makes understandable why, in periods of normal science, it happens that when a theory gets into trouble with experience, it is one or several special laws which are abandoned, not the guiding principle itself. In normal science, confronted with a predictive failure, scientists just look for another possible specialisation of the same guiding principle which aims at being empirically more successful than the previous one(s). As Kuhn remarked, giving up a guiding principle (a "schematic generalisatio," in his terms) is never the result of the application of logic (Popper's famous *modus tollens*) but rather of an increasing loss of trust in its capacity to lead us to an appropriate special law for dealing with some recalcitrant phenomena – "appropriate" meaning here that the form of the special law in question fits well into the conceptual frame of the guiding principle. When scientists abandon the hope of fixing the anomaly by modifying special laws, they abandon thereby the guiding principle and start looking for a new theoretical framework with a new guiding principle: Kuhn's scientific revolutions.

2 | OTHER EXAMPLES

Up to this point, we have discussed the meta-paradigmatic case of classical mechanics with Newton's second law as its guiding principle. But this is certainly not a singular case. As we remarked earlier, the existence of guiding principles in the sense we discuss here is characteristic of many quite developed theories that cover several different sorts of phenomena within a common frame. CPM is probably the most paradigmatic case of this sort of theory, but there are several other highly unified theories in different disciplines which prove to have a similar structure. We will briefly consider some of them.

Equilibrium thermodynamics of simple systems (ETS) is also a theory of the sort we are considering here. ETS aims at the explanation of different sorts of changes of volume, pressure, and so forth, of fluids (liquids and gases) by postulating some lawlike connections between these magnitudes and other, specifically thermodynamic magnitudes such as entropy, internal energy, mole numbers, enthalpy, absolute temperature, and others. For our present purposes, we will analyse a version of the theory in which the only primitive concepts are, besides the states of a system represented by the theory's variables, entropy (S), internal energy (U), volume (V), and the mole numbers (N_i) – the other magnitudes such as enthalpy and absolute temperature being definable in terms of the former, or being imported from other theories as in the case of pressure. ETS is also based on a very general, schematic guiding principle, which in textbooks (see, e.g., Callen, 1960 and Tisza, 1966) is often formulated as.

$$S = S(U, V, N_i).$$

This formula is an extremely succinct (and somewhat misleading) representation of ETS' guiding principle, which in a more correct and cogent way might be formulated as follows (for a completely precise version, see Balzer et al., 1987, ch. III.5):

> *GP-ETS*: *For any thermodynamic equilibrium state*, *its entropy is determined by a function depending on the internal energy*, *the volume*, *and the mole numbers of this state*. Formally: *For any equilibrium state* z, *there is a function* f, *such that*: $S(z) = f(U(z), V(z), N_i(z))$.

As in the case of CPM, this schematic guiding principle may successively be specified in different ways through a specification of the function f for different types of thermodynamic systems. Graphically, this process may be represented by a net in which different branches correspond to different kinds of functional dependence for different thermodynamic phenomena (Figure 2). In a somewhat simplified manner, this net may be represented as follows:

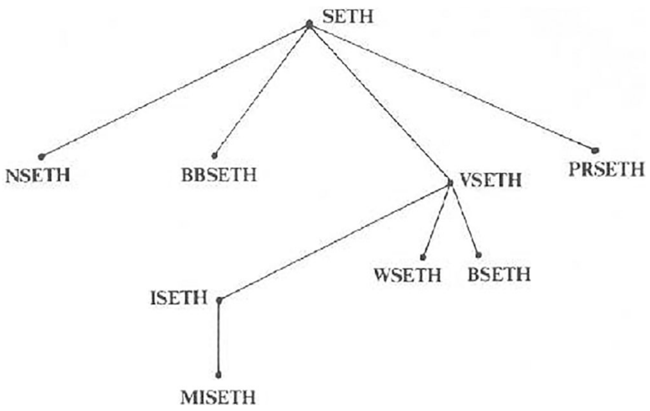

FIGURE 2 Theory net of Equilibrium Thermodynamics of Simple systems

Here, ETS stands for the net's most basic theory-element: It becomes specialised in four branches: systems where Nernst's law is relevant, black-body systems, virial systems, and systems where the so-called phase rule applies. The branch of virial systems gets in turn specialised by ideal gas systems, Van der Waals systems, and so on. (For more details, see Balzer et al., 1987, ch. III.5.) In a way similar to CPM, being committed to treat certain phenomena within ETS's frame means looking for a function that combines the relevant parameters *in a specific way* that applies successfully to the phenomena in question.

Another highly unified theory, this time within biology, is the theory of natural selection (NS). NS aims at explaining some kinds of changes in the distribution of some characteristics within a given population of organisms by appealing to a certain biological function carried out by the characteristics in question in a given environment: Those individuals carrying out that function become reproductively more successful than the others. This implicitly expresses a guiding principle that may be formulated as follows (for a more complete formulation, see Ginnobili, 2010, as well as Díez & Lorenzano, 2013):

> *GP-NS*: *The (inheritable) phenotypic characteristic C increases its chances of propagation in the environment E if it facilitates the function or behavior B leading to a higher reproductive success.*

This guiding principle may be specialised for different kinds of adaptation in different directions. For example, we may have an adaptation increasing the chances of survival for reproduction when the characteristic in question increases the chances of getting food, or else increasing the chances of avoiding predators, or else increasing the chances of successfully mating, and so forth (Figure 3). In a somewhat simplified manner, GP-NS's specialisation net looks like this[3]:

This reconstruction of NS as a GP-NS driven unified theory explicates an important feature of the theory. As is well known, adaptation is not the only explanation of the change or stabilisation of traits, other biological explanations being genetic drift, horizontal transmission, and so forth. What then is characteristic of an *adaptive* explanation, of a traits-phenomenon candidate to be explained in adaptive terms? Precisely this: To be ready to account for it within some specialisation or other of GP-NS. In the same vein as light trajectory was considered a mechanical phenomenon as far as, and until, physicists intended to account for it by a specialisation of GP-CPM, a change or a stabilisation of traits is considered an adaptive phenomenon as far as biologists intend to account for it within the framework of GP-NS. This is why the scope of NS (or of CM, or of any other guiding principle driven theory) is an *open domain*: To

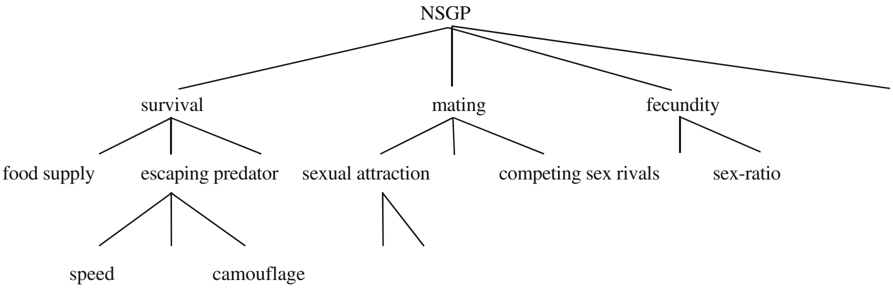

FIGURE 3 Theory net of Natural Selection

the extent that the scientific community aims to explain a phenomenon within the theory-net based on the guiding principle, the phenomenon is an *intended* application. If the explanation succeeds, then the phenomenon becomes a *successful* application. Otherwise, the phenomenon either continues being an intended yet failed application, that is, an empirical anomaly (e.g., Mercury's case above), or it is finally removed as an explanandum for the theory (light's case above).

What makes then a phenomenon a candidate for a mechanical phenomenon, or an adaptive phenomenon, and so forth, is simply the hope held by scientists (given the – according to them – relevant resemblance to other phenomena already explained) of finding out a specialisation that explains it. To be a candidate for a T-phenomenon is just to be so treated by T's scientific community. The kinematic trajectory of a pencil in one's intentionally moved hand is not an intended mechanical phenomenon because there is no attempt to account for intentional motions within GP-CM; the same applies (in the nineteenth century) to the light trajectory case that became an application of wave theory. Likewise for adaptive phenomena: for example, the dog tailless phenomenon due to our cutting a dog's tail after birth in a given dog population is not an adaptive phenomenon because biologists do not intend to account for it within the GP-NS framework; the same applies to the cheetahs case, that became an application of genetic drift (Kliman et al., 2008).

NS is not the only biological theory guided by a guiding principle: Another is (Mendelian) classical genetics (CG) (see Lorenzano, 1995 and 2000, as well as Casanueva, 2003). CG explains the statistical similarities of characteristics between ancestors and progeny by postulating the presence in both generations of some "factors" (genes) that are transmitted from the first to the second through reproduction. These factors are supposed to be responsible for the manifest characteristics (the phenotype). CG's guiding principle approximately runs as follows (for a more precise formulation, see, e.g., Lorenzano, 2000):

> *GP-CG*: *Statistically common characteristics between ancestors and progeny are due to the presence in the ancestors of some factors that they transmit to their progeny in specific ways, and that determine the manifest characteristics in such a way that the distributions of factors "concur" (in specific ways) with the distributions of the characteristics.*

As in the previous cases, this guiding principle specialises in different ways: In the present case, it may specify the number of factors involved, the different probabilistic forms of transmission of the characteristics or of the genes, and the way the genes are related to the characteristics (dominance or not) (Figure 4). The result is a theory-net with the following form (in order to simplify the exposition, we omit some details):

The first specialisation level distinguishes between those crossings where the combinations of factors are equally probable (specialisation "E") and those where they are not (specialisation

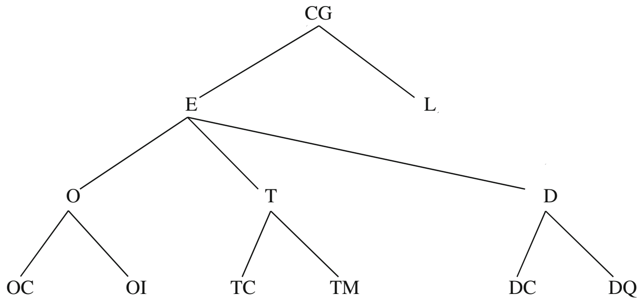

FIGURE 4 Theory net of Classical Genetics

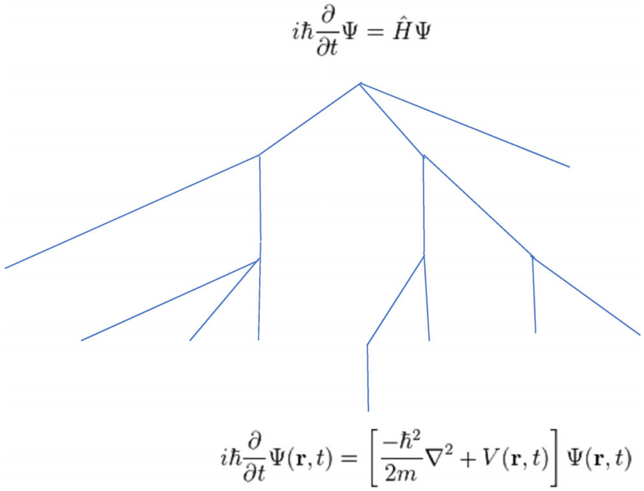

FIGURE 5 (Part of the) theory net of Quantum Mechanics

"L", which stands for "linkage"). Subsequently, they become more specialised according to the number of factors (e.g., E specialises in cases of one pair of factors, O; two pairs, T; or three pairs, D), the presence of dominance or not, and so forth (see Lorenzano, 2000 for more details).

The last case we will lay out belongs to contemporary physics. We have chosen it in order to make clear that the features of theories in basic science we have just discussed are not restricted to classical physics but show up in contemporary physical theories such as quantum mechanics (QM) as well. Although extant structuralist analyses of QM (Lastiri, 2012; Sneed, 2011) do not specify the corresponding guiding principle and the associated theory-net in the same detail as has been done in the previous examples; nevertheless, they contain some hints sufficient for suggesting that here too we have a theory-net guided by a guiding principle – in this case, Schrödinger's wave equation:

$$i\hbar\tfrac{\partial}{\partial t}\Psi = \widehat{H}\Psi.$$

This equation relates the evolution of the wave function of a given system to a Hamiltonian whose specific form varies from system to system (Figure 5). For example, for an isolated electron, it takes the form.

$$i\hbar\frac{\partial}{\partial t}\Psi(r,t)=\left[\frac{-\hbar^2}{2m}\nabla^2+V(r,t)\right]\Psi(\mathrm{r},t).$$

Different Hamiltonians for different sorts of systems generate a theory-net having, among other things, a branch with a terminal node representing the case of the free electron:

These are just some examples of theories unified within the frame of a guiding principle, in which the specifications work as different special laws for different explanations. Now, the presence of such structures is not restricted to physics or macrobiology; similar structures guided by guiding principles have been unearthed and reconstructed in astronomy (Carman, 2010), microbiology (Allewa et al., 2017a and Allewa et al., 2017b), and biochemistry (Federico & Lorenzano, 2010), as well as in some social sciences such as linguistics (Peris-Viñé, 1994) or economics (Pearce & Tuaai, 1981). It is important to note that those guiding principles need not be spelled out explicitly in a theory's standard expositions. Sometimes, they are, as in the case of Newton's second principle. In other cases, they appear in some textbooks but not in others, as it is the case of the Equation $S = S(U, V, N_i)$ for thermodynamics. In still other cases, the guiding principle is contained only implicitly in the practice of concrete explanations, as happens in the theory of natural selection or in classical genetics. In the latter cases, the philosopher's task consists in unearthing and making explicit what is only implicit in the textbooks of the discipline in question.

In our view, the notion of a guiding principle as well as its associated notion of a theory-net are useful not only to have a more thorough knowledge of a theory's inner structure but also to tackle some central problems in general and special philosophy of science, as well as to better understand some important debates that have arisen in the history of the philosophy of science. Let us briefly consider an example of each one of these areas.

3 | GENERAL PHILOSOPHY OF SCIENCE: THE CONTENT OF THEORETICAL CONCEPTS

One of the most conspicuous issues in general philosophy of science is the content of theoretical concepts, and particularly the content of concepts referring to unobservable entities, as is the case for concepts such as *force*, *entropy*, *quark*, *electromagnetic field*, *chemical affinity*, *selective adaptation*, *ethnic group*, or *utility*. The main existing proposals to deal with this issue coincide in ascribing two components to that content: one is given by the relations between any of those concepts and other concepts of the same theory or of some other theory established through lawlike propositions; we may call this the *formal component* of the concept at issue ("formal" to connote that this is the only component present in formal or non-empirical theories). The other component is given by the relationship(s) between the concept in question and those observable situations to which it is supposed to apply; we may call this its *empirical component*. The different proposals, however, diverge with respect to the particular explication they propose of the two components, especially the second. For the "received view" (see, e.g., Carnap, 1966), the content of a theoretical concept is determined by a combination of some *theoretical axioms* mutually connecting some theoretical terms (assumed to be non-observational) with some *rules of correspondence* connecting some theoretical terms with some observational terms. On the other hand, Kuhn (1970) claims that the first component is determined by what he calls *symbolic generalisations*, whereas the second component arises from the application of the symbolic generalisations to some *exemplars*, that is, empirical systems to which they are supposed to be applicable. For operationalists such as Bridgman (1951), in turn, the formal component is given by *paper and pencil operations*, whereas the empirical component is given by some *experimental operations*.

Now, for our present purposes, it is not substantial which one of the historically given explications of the formal component of theoretical terms we favour; it suffices to focus our attention on the general idea that this component depends on the mutual relationships between one theoretical concept and others as determined by their lawlike connections. The obvious question then is: Which lawlike connections actually constitute the formal component? For David Lewis (1970) the answer is quite simple: all the laws in which the concept at issue occurs at a given time are constitutive. However, this position appears to be quite unsatisfactory because it multiplies, in a quite implausible manner, the elements determining the theoretical concepts. In the course of the development of a given theory, its system of laws usually changes to a greater or lesser degree because the parameters of some laws become modified, or because some laws are replaced by others, or because new laws are introduced (within one and the same theory) to account for new phenomena. Lewis's position has the consequence that, even the slightest change in the theory's laws would imply a change in the formal component of its concepts, thereby in the concepts themselves. This is quite counter-intuitive: It implies, for example, that in the course of one century in the development of classical mechanics from Newton to, say, Laplace, the concept of mass was continuously changing because repeatedly new special laws were proposed within mechanics, or because some of their parameters were modified, or some special assumptions were given up, and so on.

One may defend an extremely fine-grained notion of concept that makes them so abundant. And this might even be of some interest for explicating some aspects of scientific practice. But we take that, be this abundant notion as it may, there is a need for another, more sparse notion of a scientific concept that explicates essential features of scientific practice, for instance that there is a relevant sense according to which Newton and, say, Laplace were using the same meaning/concept of mass. Thus, because Lewis's simple-minded characterisation of the formal content of theoretical concepts does not serve this goal, our task is to find out which laws are *really* constitutive of a given concept in this later, sparse sense. Peacocke (1999) doubts that a well-founded answer might be given to this question: If the lawlike components accepted for a concept become too specific, it is very likely that the concept loses its identity in the course of history; but, on the other hand, if we accept only a small number of them, the concept will probably lose its individuality.

The idea of having a theory-net based on a guiding principle may offer a way out of the Lewis-Peacocke challenge (see Díez, 2002): The problem has arisen under the assumption that all laws of the theory analysed should be considered equally relevant for the determination of the theoretical concepts. But the assumption that all of the theory's laws are equally significant is precisely what is subverted by the idea of a hierarchized theory-net with a guiding principle. Paraphrasing the famous slogan in George Orwell's *Animal Farm*: "All laws are lawlike, but some are more lawlike than others." Clearly, the guiding principle itself will be the most prominent instance for the determination of the formal content of the theoretical concepts. But, usually, it will not be the only lawlike statement playing this role. Some other more specific but quite important laws, with a wide scope of application, will play a similar concept-constitutive role; on the other hand, very special laws that intend to solve only very limited problems will not play that role at all. Which laws in a net are still "important enough" to constitute (part of) the formal component of the theoretical concepts is not a meaningless question, as Peacocke pretends, but it is certainly not a question that may be answered for all theories in the same way. There is no "algorithm" to answer this question. The answer will depend on a very detailed analysis, both methodological and historical, of the essential features and semantic practice of each theory. And the answer will always be (metatheoretically) hypothetical.

Take the example of classical particle mechanics and its basic mass concept. Which mechanical laws are constitutive of that concept? Undoubtedly, CPM's guiding principle, Newton's second law, is constitutive of the mass concept. If someone claimed that her mass concept has nothing to do with Newton's second law, we could certainly point to her that she has just changed the language game, that she is using (or pretending to use) a notion that has nothing to do with classical mechanics as developed from Newton on. Now, the classical mass concept presumably presupposes also some other significant lawlike constrictions besides Newton's second law, like those related to gravitation. If someone pretends that she is using the classical concept of mass but that massive bodies do not attract each other, we presumably will dismiss her contention in a way similar to the second law case. It seems to be quite plausible to contend that the assumptions that massive bodies exert mutual attractions, and that the force of attraction decreases with distance, are also constitutive of the classical mass concept together with the second law. On the other hand, that the gravitation dependence is exactly square inverse,[4] or the occurrence of a specific coefficient for the mass parameter in, say, a particular law for elastic forces, certainly will not be regarded as essentially constitutive of the general mass concept. A similar point could be made for the basic theoretical concepts appearing in the other examples of theory-nets we have laid out above. In sum, in theories having the structure of a theory-net based on a guiding principle, the latter will *always* be constitutive of the formal component of the theoretical concepts specific of that theory, and for the other (upper-level) laws appearing in the net, the question whether they also are constitutive for them will normally be a question that may be answered only through a case study involving specific methodological, semantic, and historical considerations. In any event, although the guiding principle framework does not allow for a complete general answer, the idea of more and less essential laws that it brings with does provide the metatheoretical tool for making plausible the distinction between essential and non-essential laws needed for any particular answer with regard to any particular theory.

4 | SPECIAL PHILOSOPHY OF SCIENCE: ADAPTATIONISM'S ALLEGED ANOMALY

The theory of natural selection, and adaptationism in general, from its very beginning with Darwin has been a matter of controversy and strong criticisms for several reasons; however, one that is particularly relevant from a metatheoretical perspective is its allegedly "vacuous" nature. Leaving aside the champions of creationism, many non-creationistic biologists have contended that the theory of natural selection is tautological (Peters, 1976), unable to provide genuine explanations (Jacob, 1981), circular (Gould, 1989), or trivial (Sandin, 1995). And within the philosophy of science, Popper argued that it is not a falsifiable theory but rather a piece of metaphysics (Popper 1963, 1972 , although he later modified his position).

The last and most outstanding criticism of the theory of evolution is the anti-adaptionist campaign championed by Fodor and Piatelli-Palmarini (see Fodor, 2008 as well as Fodor & Piattelli-Palmarini, 2010). Here there are two conspicuous passages:

> [T]he theory of natural selection *reduces to a banal truth*: "If a kind of creature flourishes in a kind of situation, then there must be something about such creatures (or such situations, or both) in virtue of which it does so." Well, of course there must; even a creationist could agree with that. (Fodor & Piattelli-Palmarini, 2010, 137)

Moreover,

> If, in the ecology they occupy, birds with wings are better off than birds without them, there must be something about the birds, or about the ecology, or about the two together, in virtue of which birds with wings are better off in that ecology than birds without them. That's just *a routine application of the principle of sufficient reason*. (Ibd, 148)

The core of their criticism is that, unlike in a truly scientific theory, NS does not contain any statement of *adaptive nature* that might appear to have *counterfactual import* and be something *more than a mere truism*.

Now, the notions of guiding principles and theory-nets help us in clarifying this issue too.[5] To put it briefly, the mistake in the criticism made by Fodor and Piatelli-Palmarini to NS consists in not being aware of the fact that NS is a case of a highly unified general theory covered by a highly abstract guiding principle, comparable to CPM, as we have already argued above.

It is true that all adaptive explanations do not share anything literally identical in their explanantia. Let us see some paradigmatic examples (for simplicity's sake, we present here these explanations summarised as inferences with the explanans as the premises/antecedent and the explanandum as the conclusion/consequent; nothing hinges on this simplification for our present purposes[6]).

GiraffNeck giraffes.
IF (1) in context C giraffes get food supply only from tall trees.
(2) long neck facilitates reaching tall trees.
(3) length of the neck is transmitted with random variation to the next generation.
(4) giraffes get energy by food supply.
(5) energy supply is beneficial for differential reproduction.
THEN (6) the proportion of long neck giraffes increases in C

Zebra Lion:
IF (1) in context C zebras are predated only by lions.
(2) zebra speed is transmitted with random variation to the next generation.
(3) zebras escape lions by running.
(4) escaping predators is beneficial for differential reproduction.
THEN (5) the proportion of fast zebras increases in *C* wrt slow zebras.

BlackMoths:
IF (1) the majority of moths living on tree trunks in the Sheffield area in the late 1950s had white wings.
(2) due to industrial pollution during the 1960s, the tree trunks in Sheffield area changed from clear to dark.
(3) wing colour is transmitted with random variation to the next generation.
(4) moths escape predators by camouflaging.
(5) escaping predators is beneficial for differential reproduction.
THEN (6) moths living in the Sheffield area changed from white to dark wings during the 1960s.

SexRatio.
IF (1) in context *C*, mating is random.
(2) in *C*, cost per son = cost per daughter.
(3) sex ratio reproduction is transmitted, with random variation, through generations.
(4) mother's benefit provided per son/daughter is son's/daughter's average reproductive contribution.
(5) maximising reproductive-energy benefit is beneficial for differential reproduction.
THEN (6) birth sex-ratio approximates 50–50.

As becomes apparent, there is nothing literally identical shared by these explanantia; these explanations do not have any shared premise. Nevertheless, a closer look reveals that they *do* share something, something that, contrary to Fodor and Piattelly-Palmarini, has counterfactual import, is of adaptive nature, and is not a mere truism; namely, their explanans include, together with initial conditions, a particular specification of NS guiding principle for the explanandum in point. In *GiraffNeck*, (1) and (2) specify that in the given context the trait in point (long neck) is good for getting food; (3) and (4) that getting food is good for a function, that is, energy supply, and beneficial for differential reproduction; and the conclusion establishes that all this implies (ceteris paribus) the expansion of the trait in the population. All other cases also include in their explanans the specification of the trait, in the given context, that facilitates a function that is beneficial for differential reproduction: running velocity wrt the function of escaping predators by running, moths' colour wrt the function of escaping predators trough camouflaging, and so forth. All these are special applications, with counterfactual import, of the general GP-NS to the explanandum in point. Thus, GP-NS is no more a banal truism than GP-CM. Both principles, if considered alone, are quasi-empty or empirically non-restrict. But both become testable and refutable when applied through some specific specialisation. Thus, contrary to what Fodor and Piatelli-Palmarini claim, NS is not a theory methodologically/epistemically less decent than CM. Both, as cases of highly unified theories, are driven by a guiding principle that connects different applications through different specialised counterfactual generalisations that have in common precisely the characteristic of being different specialisations of the same guiding principle.

5 | HISTORY OF PHILOSOPHY OF SCIENCE: THE POPPER-KUHN CONTROVERSY ABOUT FALSIFICATIONISM AND THE RATIONALITY OF NORMAL SCIENCE

So far, we have shown that the notions of guiding principle and theory-net prove to be fruitful to shed light on some issues in both general and special philosophy of science. We believe that they may also help understanding better some controversies in the history of philosophy of science, as the Popper-Kuhn controversy about falsificationism and the rationality of normal scienc proves.

The following quotations show the degree of belligerency and misunderstanding attained by the controversy between Popper and Kuhn about falsificationism and the alleged (ir)rationality of normal science: Kuhn claims that

> Though he is not a naïve falsificationist, Sir Karl may, I suggest, legitimately be treated as one. (Kuhn, 1970, p.14)

To which Popper counters:

> This passage is really astonishing. It is exactly like saying: "Although he is not a murderer, Sir Karl may, I suggest, legitimately be treated as one. (Popper 1983 [1956], p. xxxiv)

When confronted with these and similar passages in the controversy, we cannot avoid the impression that there is some implicit element that hinders mutual understanding. The notion of a theory-net as based on a guiding principle, which is implicit in Kuhn's theory concept but absent in Popper, is fundamental in order to understand the terms of the debate.[7] This notion allows to diagnose that Popper has a point in his favour but that it is Kuhn, after all, who provides the right picture – even if in a blurred way. Although the controversy is supposedly about the (ir)rationality of the average normal scientist, in fact the background of the discrepancy between Popper and Kuhn is related to the theory concept that each author presupposes as the object of acceptance/rejection by a normal scientist.

Let us insert Kuhn's previous quotation into its wider context:

> Sir Karl is not, of course, a naive falsificationist. He knows all that has just been said and has emphasised it from the beginning of his career. Very early in his LSD he says that "[…] no conclusive disproof of a theory can ever be produced […]." Statements like this display one more parallel between Sir Karl's view of science and my own, but what we make of them could scarcely be more different. For my view they are fundamental […]. For Sir Karl's, in contrast, they are an essential qualification which threatens the integrity of his basic position. Having barred conclusive disproof, he has provided no substitute for it, and the relation he does employ remains that of logical falsification. *Though he is not a naive falsificationist*, *Sir Karl may*, *I suggest*, *legitimately be treated as one*. (Kuhn, 1970, 14, our emphasis)

Is Kuhn unfair to Popper? Although the latter claims that his falsificationism is not naïve, we find in him some passages as the following:

> [T]he "normal" scientist, as Kuhn describes him, is a person one ought to be sorry for. […] He has been taught in a dogmatic spirit: he is a victim of indoctrination. [… And his attitude] a danger to science and, indeed, to our civilization." (Popper, 1970, 52-53)

Clearly, Popper is here criticising Kuhn's normal scientist as someone who, even when confronted with some anomalies in her paradigm, sticks to it and tries to repair (or forget) the anomalies.

Taking into account the notion of an advanced scientific theory as a structure having the form of a net with a guiding principle, it is plausible to explain the terms of the controversy between Popper and Kuhn by assuming that the idea of a scientific theory Kuhn has in mind is akin (although in a fuzzy way) to our notion of a theory-net. On the other hand, Popper's theory concept does not take the form of a hierarchized net but is rather a monolithic entity, as is characteristic of the idea of a scientific theory within the received view.

Our notion of a hierarchized theory-net allows for distinguishing, within a given scientific theory, those portions of it that are "essential" in the sense that if we give them up, we give up the theory as a whole, from those other portions that are "accidental" in the sense that they might be modified, or even given up completely, in the course of historical evolution while preserving the theory's genidentity. Relying on this theory concept, we may then distinguish between a static or synchronic notion of a theory and its dynamic or diachronic counterpart. The first corresponds to a snapshot of a theory-net, whereas the second corresponds to a sequence of theory-nets in historical time, all of them having an essential part in common. The latter is what metatheoretical structuralists have characterised as a *theory-evolution* (for more details, see Balzer et al., 1987, ch. V).

Within this conceptual framework, it is natural to distinguish two kinds of theoretical changes: intra-theoretical changes (roughly corresponding to Kuhn'snormal science) on the one hand, and inter-theoretical changes (which might correspond to Kuhn's "revolutions"). We have a "normal scientific" intra-theoretical change, that is, a theory-evolution in the structuralist sense, when the changes affecting a theory do not impinge on the theory's essential part, that is, its guiding principle, the nomic constraints on its theoretical concepts, and its paradigmatic applications. When the changes impinge on some of these essential components (usually all of them at once), we are confronted with a theoretical revolution, which means the termination of one theory-evolution and the beginning of another one.

Having these distinctions in mind, we may restate the contentious issues about falsificationism and the rationality of normal science. Falsificationism roughly claims that (FALS) "for logical reasons, theories have to be abandoned when they get falsified, that is, when they make wrong predictions." However, if we take our previous considerations into account, we see that FALS is an ambiguous statement because we are confronted with two different notions of a theory: a synchronic and a diachronic one. To supersede this ambiguity, we may consider two different versions of falsificationism: the synchronic one (S-FALS) and the diachronic one (D-FALS):

(S-FALS) Theories in the synchronic sense have to be given up for logical reasons when they get anomalies.

(D-FALS) Theories in the diachronic sense have to be given up for logical reasons when they get anomalies (in a particular stage of their evolution).

Having thus eliminated the ambiguity, we can see that (S-FALS) is true, as Popper claims – this is the grain of truth in his position: The theory-net confronted with an anomaly cannot be kept the way it is. And he is right: It is logic that commits us to try to modify the net (*epistemically* speaking, although as long as one does not find a correct modification, *pragmatically* it is of course reasonable to maintain the S-theory).

With respect to theories in the diachronic sense, however, D-FALS is wrong, as Kuhn emphasises and Popper rejects. When we are confronted with an anomaly within a paradigm, logic commits us to do something, but this something does not necessarily mean to give up the paradigm: We may try to *repair* the paradigm by replacing some (secondary) parts of it by other (secondary) parts.[8] The normal scientist *may* behave irrationally for some other reasons but not (as Popper suggests) because she does not give up the paradigm – as a whole – when confronted with the first anomalies. It is possible that Popper would have agreed with this point were the issue presented to him in these terms, but at the time he was writing he did not have the required conceptual tools for it, which means that he did not have the required conceptual tools for not defending a naïve falsificationism. It is for this reason that Kuhn is right when pointing to the fact that Popper remains a naïve falsificationist even though he claims not to be one. This said, it is true that Kuhn himself does not articulate his position in the clearest manner, nor is he able to identify what we take to be the main source of misunderstanding (remember Kuhn's own confusing diagnosis: "our intentions are often quite different when we say the same things"). His notions of paradigm/disciplinary matrix and normal science contain the core ideas for a correct explication of rationality in normal science, but his presentation of such ideas is often not clear enough. We think that the structuralist notions of guiding principle and theory-net provide better explications of such ideas and make completely clear the diagnosis of the disagreement between Popper and Kuhn.[9]

6 | CONCLUDING REMARKS

Having seen the essential role guiding principles play in advanced scientific theories and how their nature helps to clarify the terms of some prominent issues in philosophy of science, we might be tempted to try to provide a formal definition of what a guiding principle *is*. That is, we might be tempted to look for a definition of the form: "*P* is a guiding principle iff *P* satisfies the conditions (a), (b), (c), …" Now, after some decades of failures with respect to similar concepts in the philosophy of science, we should *not* expect that this kind of endeavour might be more successful in the case of the general notion of a guiding principle. As in other similar cases, what we may detect here is, on the one hand, something like "family resemblances" between concrete cases of doubtless guiding principles, and, on the other hand, some *symptoms* that might make plausible the contention that a given law in a given theory should be labelled "guiding principle." Let us give a list of such symptoms because they have been made plausible by the discussion in the foregoing sections (see Díez and Moulines 2019 and Lorenzano, 2020 for a detailed discussion of some of these features):

1. GPs are synoptic propositions: They interconnect all (or almost all) basic concepts of the theory they guide.
2. They are schematic in Kuhn's sense as laid out above, or to put it in somewhat different terms, they are empirically non-restricted (i.e., they cannot be falsified in isolation, only through some of their specialisations).
3. Often, their explicit formulation in terms of formal logic requires the use of existential quantifiers at the beginning of the proposition (a feature which, by the way, explains their non-restricted nature). In particularly characteristic examples of guiding principles (remember classical mechanics and equilibrium thermodynamics), the existential quantifiers run over functions of functions ("functionals").
4. GPs are supposed to be applicable to all intended applications of the theory they guide. That is, those scientists who are committed to the theory in question *try* to apply the theory's characteristic GP to all the empirical applications they are interested in (this is a highly pragmatic condition).
5. They are constitutive of the formal content of the theory's theoretical concepts.

As the discussion in previous sections illustrates, all these symptoms, although insufficient to characterise univocally the notion at issue, are nevertheless quite significant to understand the nature, role, and structure of guiding principles and guiding principle-driven theories. There is a general additional feature of guiding principles that is important in order to understand them and is partially responsible for the difficulties in explicating their nature, namely, their highly pragmatic character. For instance, take the difference between Newton's second law, that is, GP-CPM, and the law of gravitation. Both are synoptic in the abovementioned sense, but the former and not the latter is a guiding principle. This means, for example, that whereas the second law is intended to apply to all of CM's intended applications, the law of gravitation is not so; for instance, the laws of the different varieties of harmonic oscillators have their own mechanical application often independent of gravitational forces.[10] One might claim that here we have the *explication* of their difference: the second law is of intended application to all systems, whereas the law of gravitation is not; this is *why* the former is a guiding principle, whereas the second is not. Things are not that easy, however, because the conceptual dependence is the other way around: it is because the second law is a guiding principle, whereas the law of gravitation is not, that the former and not the latter is of general application. That is, the general applicability does not *explicate* the character of guiding principles; it is part of what they consist of and, so, what demands explication. But the only general explication is the scientific practice itself of trying to apply it to all *mechanical* systems (that is, the scientific community considers something a mechanical phenomenon *by trying to apply* – a specific specialisation of – the second law to it). The same applies to the family resemblance between special laws. One could, for instance, mechanically account for diffraction if no restrictions were imposed on the mathematical form and combination of mechanical laws, that is, if any law were accepted, no matter how "mathematically crazy" it was (see Díez, 2014). But scientists do not accept any law; they accept only laws that "resemble enough" each other, a feature that leaves plenty of room for quite different mathematical laws but not for "any" kind. And there is no further *general* conceptual explication of such a fact. It simply is pragmatically the case that in a given theory some constraints on the form of special laws are implicitly followed/assumed. Guiding principles, and their associated "acceptable" specialisations, are two aspects of scientific practice whose strong pragmatic nature makes it impossible a complete conceptual explication.

In sum, the notion of a guiding principle is crucial to understand the structure and functioning of mature theories of empirical science having a high degree of unification and of explanatory power. The role of guiding principles consists in establishing once and for all the parameters and the explanatory frame the scientists involved in the application of a given theory *should* use (in this sense, one might say that guiding principles also have a prescriptive character.) A guiding principle *alone* explains almost nothing, and it certainly does not predict anything. But it is substantial in guiding the scientists committed to it to find the appropriate special laws that explain and predict things. We take this also to show that, in our current days of scepticism about the plausibility and fruitfulness of analysis of theories and their structural features, the case of guiding principles and their associated net-like structure demonstrates that such analysis is still not only viable but also quite useful for explicating important features of scientific practice and of the philosophical reflection on it.

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ENDNOTES

[1] See Moulines (1978/1984), Moulines (1979), Balzer and Moulines (1981).

[2] Although the basic idea is Kuhn's, he neither clarifies their "schematic" nature nor elucidates their difference with the "detailed symbolic expressions" and its connection with the structure of paradigms / disciplinary matrices. These are the main aspects that the following structuralist explication improves (Kuhn, 1976 himself acknowledges this and claims that the structuralist formalisms is the approach that captures his proposal best).

[3] Note that we are *not* saying that NS is the only biological theory explaining the distribution of characteristics; some other mechanisms may be relevant too. But this is not the place to discuss the issue in detail.

[4] Clairaut for the orbit of the moon in the eighteenth century, and other physicists (Holzmuller, Liman, Levi, Hall) for the anomaly of Mercury in the nineteenth century, proposed "slight" changes in the law of gravitation (cf. Giné, 2008), and nobody responded by charging them of making a revolutionary proposal that implied changing the meaning of *mass*.

[5] For a more detailed exposition of this point, see Díez & Lorenzano, 2013.

[6] These inferences are valid only upon a ceteris paribus conditions. For instance, in the giraffes case, the conclusion holds if there is no condition that makes long necks prejudicial for survival (e.g., the presence of a specific predator that is more efficient hunting long neck giraffes; we thank an anonymous reviewer for pointing this out). This is true, but it applies to all explanations, mechanical ones included (e.g., in inferring a trajectory of a planet, we assume that there are no strange bodies attracting it). Because a detailed reconstruction of this feature goes beyond scope of this paper, and nothing in what follows hinges on it, this simplified version suffices.

[7] See Díez, 2007 for a detailed analysis of this controversy and the suggested diagnosis.

[8] This includes the cases, also commented by Kuhn, of targeting auxiliary hypotheses as the responsible of the failing prediction; this make it necessary to include some intertheoretical links as elements of the theory nets, which structuralism already does for independent reasons (cf. Balzer et al., 1987 ch. 6).

[9] We are *no*t claiming that Kuhn himself *could* not have provided a similar reconstruction of this controversy with Popper *had* he clearly elaborated his own conceptions. *This* is precisely our point, and what we think Kuhn is implicitly acknowledging when he later claims that the Sneedian formalism is which best captures his ideas (see fn 3 above).

[10] That the mechanical study of a mechanical system is independent of gravitation does not mean of course that gravitation does not apply to its compound particles but simply that the mechanical explanation/treatment of the phenomenon does not take gravitational forces into account, presumably because they are negligible in the context.

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