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## ***Redesigning the argument from design.***

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**Abstract.** This paper questions the “arguments from design” that inferred from the functions of organism, their structure or their fit to their environment the fact that they have been designed by an intelligent architect. These arguments are very old, and have been pervasive in philosophy and natural history since Antiquity. Each version connects in some way functions, structure, complexity, with randomness and low probability. Darwin claimed to have solved this argument, because natural selection eliminate the need to appeal to a designer. After having distinguished several types of arguments, regarding whether they consider mostly adaptation and contrivances, or mostly complexity, I analyze the rational core of these arguments in terms of computational notions of complexity and randomness. In the last section, I show the reason why natural selection indeed solves the design argument ; I finally focus on the link between complex adaptation and cumulative selection, and draws some conclusions regarding the relation between chance and selection in current evolutionary biology.

For Darwin, the theory of evolution by natural selection was in part aiming at explaining the *design* of organisms, that is, the fact that they seem to have been designed, a fact which is manifest in the *contrivances* exhibited by the various plants and animals: he entitled his last book *Various Contrivances by which British and Foreign Orchids are Fertilized by Insects*, The issue of design as addressed by Darwin was a longstanding problem for natural history and the life sciences, that he thought to have solved, as he said in his *Autobiography*: "The old argument of design in nature, as given by Paley, which formerly seemed to me so conclusive, fails, now that the law of natural selection has been discovered" (Darwin 1869).

The history of anatomy and physiology indeed displayed a massive use of arguments from design and inferences to design, with important historical shifts between old and modern physiology (Cunningham, 2000, 2003). The main formulation of this problem in Darwin's time was Paley's *Natural theology*, and in general the *Bridgewater Treatises* written by theologians and biologists – which also provided a theological answer. The very general formulation of it was something like: organisms are so complex, exhibit so much “exquisite contrivances”, that they cannot be here by chance, so there should be a designer<sup>1</sup>. The following paper aims at formulating in more contemporary terms this problem of design, pinpointing the rational core of some arguments from design, and indicating why natural selection is a solution.

However, even though the so-called argument from design - going from a salient design in organisms to conclude to a divine designer -, is overwhelming and has been constantly used from Stoic thinkers like Cicero up to recent supporters of Intelligent Design (throughout many naturalists and philosophers), it is not clear that it is one and the same argument all over the place. Even when – following a distinction between types of design argument made by Gillespie (1990) - we concentrate on arguments from *biological design*, leaving aside an important kind of argument focusing on the regular design of the stars and the planets and generally the clocklike aspect of the universe as a whole to conclude in favor of a divine architect, it appears that distinct aspects of the phenomenon of organisms are under focus of distinct varieties of the argument: sometimes we are told about complexity, some other times we are told about the fit between organisms and their milieu, etc.

The question of this paper is therefore twofold: what is the bulk of the arguments from design, i.e. the (non-) connection between *design* and *chance*, and can it be made explicit and rigorous ? If

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<sup>1</sup> This was sometimes expressed through an appeal to analogy with an artifact, but this appeal is not always present, and sometimes rather pedagogical – see below.

there are various brands of arguments, what are their respective bases ? and finally, in what sense is it legitimate to say that Darwinian evolution answers the argument from design ?

## **1. Design and complexity.**

### *1.1 The intuitive connection*

*Design* means both an intentionality (“X has been designed to...”) and a holistic integration (“X has a design...”). In the varieties of design argument that occurred in the history of natural history and natural theology – from Cicero to Paley, at least -, both are entangled: organisms are such that they have an integrated structure (*a design*), that is adjusted to their environment and therefore allows for some vital functions, and that therefore cannot be otherwise than *designed*, since we don’t conceive of any other way for them to be there. It is an *argument*, because to some extent it infers, from the first sense (the “holistic integration”) of design which can be measured and attested, the second one (“being designed”).

Here are several historical formulations. In *On the nature of gods*, Cicero writes :

“When you see a sundial or a water-clock, you see that it *tells the time by design and not by chance*. How then can you imagine that the universe as a whole is devoid of purpose and intelligence, when it embraces everything, including these artifacts themselves and their artificers?”

This focuses on the function (telling time) and makes an analogy with an artifact. These features are also met much later by Paley, but with an emphasis, precisely, on the design of the artifact (a watch) :

“Suppose I found a watch upon the ground, and it should be inquired how the watch happened to be in that place, I should hardly think ... that, for anything I knew, the watch might have always been there. Yet why should not this answer serve for the watch as well as for [a] stone?... For this reason, and for no other; namely, that, if the different parts had been differently shaped from what they are, if a different size from what they are, or placed after any other manner, or in any order than that in which they are placed, either no motion at all would have been carried on in the machine, or none which would have answered the use that is now served by it.” (Paley 1802, 66)

The example of the watch (a remote descendant of Cicero’s clepsydra) is overwhelming in the literature; its rhetorical appeal may come from the fact that its function, as well as its being-designed, are obvious, combined with the fact that the mechanism of the watch is at the same time very precise and complex.

As indicated, the design could be the design of the whole world ; however since the 18th century treatises on natural theology insist on the design of *organisms*; Paley, and then Darwin, inherit this point. What characterizes their design includes the fact that they have *functions* – and more precisely, that they seem to be *designed to survive*. But Paley’s book is an extended consideration of *many* forms of designed biological features – internal organs, complex apparatuses, etc. and strengthens the initial argument by emphasizing the multiplicity and variety of animal designs, which should be even more convincing (regarding design) than just one organism :

“when the multitude of animals is considered, the number of parts in each, their figure and fitness, the faculties depending upon them, the variety of species, the complexity of structure, the success, in so many cases, and felicity of the result, we can never reflect, without the profoundest adoration, upon the character of that Being from whom all these things have proceeded.” (Paley, 1802, 489)

Actually, some of the design arguments infer from the function (telling time) to the design and then the designer (see Cicero); but as Paley recognizes, *complexity* plays a role here, because the argument will not be convincing if the mechanism implementing the function is very simple: “Now we deduce design from, relation, aptitude, and correspondence of parts. *Some degree therefore of complexity is necessary* to render a subject fit for this species of argument.” (Paley, 1802, 410, my emphasis). Importantly, one of the connections implicit in many arguments from design often relies upon some idea of *complexity*: the design (i.e. structure, holistic integration) is *complex*, and because of this complexity one infers the designedness (intention), through the impossibility of getting such complexity by chance. The watch found on a beach is not only functional, it’s also *too complex* to have been built by chance.

In the *Dialogues on natural religion*, Hume long before Paley set the *analogy* argument that compares the watch and an organism, under scrutiny and has shown many of its flaws; Kant also dismissed it in the *Third Critique* (Kant 1790, §§82-83). But notice that the role of the analogy in the arguments from design is not straightforward. The analogy stands between the watch and craftsman, on the one hand, and an organism (or the whole world, depending on the versions) and an intelligent architect, on the other hand. Because the watch has a specific relation to the craftsman (namely: designing), and because the organism (resp. the universe) exhibits the same features as the watch, the organism (resp. the universe) should have the same designing relation to an agent. But the reasons for asserting a relation between a watch and the craftsman are at least twofold :

- a) we may simply know, empirically, that watches are made by craftsmen – and therefore, use this knowledge to apply it, by analogy, to the case of the organism;
- b) but it can also be the case that we infer, from some properties of the watch, the fact that there is a designer – the existence of a designer being a corroboration of the inference, exactly like, in science, we predict some event on the basis of a theory, and use the attestation of this event to confirm the theory.

In this second case, the fact that the design inference in the case of the watch is corroborated, entitles us - through the analogy - to postulate the validity of a comparable inference in the case of the organism. Hence in version (b) the relationship between design of the watch and designer is already the target of an inference that starts by considering the structural and functional properties of the watch, and then infer that such features could not be here by chance. Kant describes such an inference (proper to the side of the watch) with his example of a regular hexagon found on the sand:

“If someone were to perceive a geometrical figure, for instance a regular hexagon, drawn in the sand in an apparently uninhabited land, his reflection, working with a concept of it, would become aware of the unity of the principle of its generation by means of reason, even if only obscurely, and thus, in accordance with this, would not be able to judge as a ground of the possibility of such a shape the sand, the nearby sea, the wind, the footprints of any known animals, or any other non- rational cause, *because the contingency of coinciding with such a concept, which is possible only in reason, would seem to him so infinitely great that it would be just as good as if there were no natural law of nature*, consequently no cause in nature acting merely mechanically, and as if the concept of such an object could be regarded as a concept that can be given only by reason and only by reason compared with the object, thus as if only reason can contain the causality for such an effect, consequently that this object must be thoroughly regarded as an end, but not a natural end, i.e., as a product of art (vestigium hominis video).” (Kant 1790, §62, 370)

Notice, first, that only the design is apparent here, since the regular hexagon has no usefulness; second, that Kant's formulation is radical: if this hexagon were here by chance, it could be also possible (since it's equally improbable) that the lawful arrangement of the physical nature were just a fluke, no actual law supporting the universe, which is of course obviously wrong. Thus the classical design arguments have indeed two moments: a. the similarity between watches and organisms in terms of structure and functions; and b. the inference, from a specific complex and functional structure of watch, to the fact that it has been designed. As indicated by Kant, this reasoning could therefore go directly, in fact, from the organism to the design, the reference to the watch being only a rhetorical or pedagogical tool.

However inconclusive according to Hume, arguments from design were still targeted by Darwin, to the extent that natural selection is given as an alternative explanation of design – as indicates the sentence quoted above, from his *Autobiography*. To dismiss this kind of reasoning, the *Origin of species* included a chapter wholly devoted to show that evolutionary theory could explain *one* famous complex organ, the one which was paradigmatically evoked by supporters of the design argument, namely the eye. We now know now a simulation of the evolution of the eye (Nilsson and Pelger, 1994) in terms of genetic algorithms which supports Darwin's initial hypothetical scenario: slightly improved variations, continuously scrutinized and retained by natural selection, can lead to a complex adaptation as striking as the mammal's eye. The present paper aims at understanding to what extent the design argument can be explicated as one *argument*, and how evolution by natural selection as it is conceived of by Darwin - modeled by the current theory of evolutionary biology and implemented for instance in the Nilsson and Polger simulation - answers the design argument.

This classical design argument, possibly using an analogy between artefacts like watches and organisms, aims at proving the fact that organisms in nature require a designer. "Design" having two senses, such argument from design actually envelops two things: the fact that organisms have a *complex structure*, and the fact that they are designed *to fit their environment* (in the same way as a watch is designed to tell time). This latter idea is in general named by the word "adaptation", which proves here crucial, and bears subtle relationship with notion of complexity, that we have to explicate in the next subsections.

### *1.2 Adaptation, Darwinian style*

We must first focus on the concept of adaptation, which for classical naturalists of the 17<sup>th</sup> or 18<sup>th</sup> century meant the fit between organisms and their environments (Balan 1979, Amundson 1996), attested by myriads of organismal features such as the webbed feet of ducks that allow them to crawl on water, mammals' lashes that consistently protect the eyes, etc. It is now often thought by biologists and philosophers of biology that natural selection somehow explains adaptation (Sober 1984; Brandon 1990; Burian 1983); more precisely, what Darwin brought about is an understanding of *adaptations* - namely, traits that are adaptations - as products of natural selection<sup>2</sup>. This is a view of what "to be an adaptation" means. Two things shall be noticed here regarding this Darwinian, modern understanding of adaptation:

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<sup>2</sup> In the chapter 6 of the *Origin*, Darwin writes a sentence which conveys the idea that « adaptation » is a concept characterizing parts, and that « adaptations » is a word that itself names some parts. One reads : "For natural selection acts by either now adapting the varying parts of each being to its organic and inorganic conditions of life; or by having adapted them during long-past periods of time: the adaptations being aided in some cases by use and disuse, being slightly affected by the direct action of the external conditions of life, and being in all cases subjected to the several laws of growth." (Darwin, 1809, chapter 6, section "Summary")

i. “Adaptations” are traits; the mechanism of natural selection, that is, basically random variations and retaining of traits that provide the highest reproductive chances to their bearer, leads to traits that make the organism well fitted to its environment, since this fit allows it to best cope with the environmental demands (Huneman 2014b). “Adaptedness” of *organisms*, namely the adjustment between an organism and its environment, which is manifest in features such as the match between the polar bear and the colour of its environment and was targeted by many design arguments since the analogy generally connects whole organisms with watches - has to be distinguished from the “adaptations”, in the sense of *traits* resulting from natural selection.

ii. This *definition* of adaptation is not an *explanation* of all adaptations. Actually, it redefines what adaptations are. Now, when an adaptation is found, provided that we know a criterion to identify it – another issue we turn to below in this section – we have to explain it; and selective pressures are the explanations for this adaptations. (They instantiate the environmental demands). One can identify a trait as an adaptation without being able to find the reasons for this adaptation, in other words to explain it as an adaptation (Endler 1986, Brandon 1990, Wade and Kalisz 1990)

It is to be noticed that this definition of adaptation is challenged by several behavioural ecologists, who argued that “X is an adaptation” is not, as Brandon (1990) says of the above definition, a “historical statement” but a judgment often issued with no consideration for history. They argue that when they are interested in the maintenance of a trait, for example, the timing of a foraging behavior in a given species, or the life history parameters such as reproduction time or lifespan, behavioural ecologists rather compare traits values (they call it “strategies”) and assess their payoff in fitness; the one with highest fitness is predicted to be the one which is maintained (Reeve and Sherman 1993). Those maintained traits are “adaptations”, not in the sense of a historical statement, but in the sense of a comparison of fitness values. Convincingly, they add that “adaptation” is a historical concept especially when scientists question *origins* of traits rather than their *maintenance* – for instance, paleobiologists. Later on, Brandon (2013) made the case that both these historical and ahistorical definitions of function and adaptation are complementary, and pertain to complementary research strategies.

From our viewpoint, notwithstanding the controversies all evolutionary biologists agree on an intrinsic link between their concept of adaptation and the concepts of fitness and natural selection – the only question is the precise nature of this link, and it is reasonable to say that it may vary according to distinct explanatory strategies or research questions. It is such a link that has been discovered by Darwin, and to some extent answers the arguments from design, which will be explicated in the two next sections. For any Darwinian, when we say that “X is an adaptation”, we are saying something about the fact that its presence calls for an explanation that includes, at some level and in some form, natural selection.

This shows that Darwin already answers the simplest form of arguments from design, that infers from an apparent *function* – “telling time”, for the watch; “allowing the animal to fly”, for the wings – the existence of a *designer*: functions are in fact adaptations, i.e. the result of natural selection, and therefore an evidence for the effect of natural selection. If the argument from design was simply centered on an analogy between any functional feature and telling time, indicated by Cicero, then Darwin would have given an answer simple to understand; however the argument is manifold, and the rest of this paper addresses its other modalities.

### 1.3. Adaptation and contrivances.

In the evolutionary view, *adaptations* – as compared to the adaptedness of organisms - are in a sense what comes first because they are what natural selection explains: the modern evolutionary theory considers trait types (genotypes or phenotypes) and the processes according to which some trait values are settled in a population or some alleles fixed in the population. This idea is implied by the fact that the fitness of *traits* (i.e., the expectancy of the distribution of offspring number of all individuals that share a trait) rather than fitness of *organisms* (Orr 1990) is what is predictive in evolutionary models, which are intended to explain the evolution of a trait. Hence, when they are adaptations traits are here through natural selection. Being there because of natural selection for some effects, it is also common to say that their *function* is this effect; such understanding of “function” is called “etiologial view of functions” (Wright 1973, Millikan 1989, Huneman 2013).

A straightforward way to see the adaptedness of organisms consists thereby in seeing them as consequences of the sum of these adaptations that are the traits; in this sense, organisms are indeed the result of natural selection, because they are, as Huxley (1942) said, “bundles of adaptations”. The Modern Synthesis, by viewing evolution as acting on genes which are *prima facie* independent units, enhances this sort of atomistic view of organisms as composed of traits<sup>3</sup>. However this is not so simple because the traits are not independently evolved to face some specific environmental demands: at least, each trait may compete with other traits of an organism for energetic or metabolic resources – therefore there is a trade-off between their values, and the trait as adaptation is not the theoretically optimal value of the trait regarding an environmental demand. Adaptedness of organisms has therefore to integrate those trade-offs between traits. And as Gould and Lewontin (1979) famously pointed out, it’s not even the case that these trade-offs suffice to make organisms mere bundled consequences of the adaptations: other *constraints*, such as developmental constraints or simply inertia or phylogenetic history, bear on the overall organisms<sup>4</sup>.

The simple lesson to take here is that the traits of organisms are *often* adaptations, and the *set* of traits proper to an organism seem in any case to be *contrived* together to a common purpose – which is the survival and reproduction of the organism. This is exactly what strikes Darwin as natural historian – especially when he was writing about orchids (Darwin 1862) and what he named the “contrivances through which orchids reproduce” – this latter term being much insisted on by Paley, as a pillar of the analogical argument: “every indication of contrivance, every manifestation of design, which existed in the watch, exists in the works of nature; with the difference, on the side of nature, of being greater and more, and that in a degree which exceeds all computation. I mean that the contrivances of nature surpass the contrivances of art, in the complexity, subtlety, and curiosity of the mechanism” (Paley 1802, 19).

The design of organisms, therefore, consists of the parts being both *adapted* to specific environmental demands and *contrived* (i.e. adapted to one another). Arguments from design are based on this notion of design, and Darwinian evolution answered it by explaining adaptation in terms of natural selection (Gardner 2009).

The overall problem of the design of organisms as Darwin inherited it includes therefore three terms: *adaptedness* (fit between organism and environment); *adaptations* (trait that fulfills a function contributing to this adaptedness); and *contrivances* (all traits seem to be contrived). But we have not yet grasped the whole extent of the traditional arguments from design.

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<sup>3</sup> This simplification has been famously criticized throughout the Modern Synthesis by Ernst Mayr under the name of “beanbag genetics”.

<sup>4</sup> See Mayr (1983) for an answer, Godfrey-Smith (2000) for a reflection about the various meanings of “adaptationism”, and Huneman (2014) for a reconceptualisation from the view point of the Formal Darwinism elaborated by Grafen (2002).

#### 1.4. Complexity.

Not all adaptations are equal; some of them, like the eye, are more complex than others like skin colour or size. Only the former have the appeal to make us question their deepest source or reason, and they will be crucial in the argument from design. What mattered for Paley and natural theologians or some biologists – especially the ones writing those *Bridgewater treatises*, so influential in the times of Darwin – , and what was understood in an alternative way by Darwin through natural selection, was precisely those *complex adaptations of organisms*. Long after Paley, the prominent evolutionary biologist G.C. Williams (1992) considers that complex adaptations precisely indicate features that require an explanation by natural selection.

Williams' groundbreaking book *Adaptation and natural selection* (1966) indeed questioned the very reasons for which we should say that a given trait is an adaptation. Adaptation, recall, is linked to natural selection in a way that being an adaptation calls for an explanation which includes selection. He famously estimated that “adaptation” is an “onerous” concept - meaning that one should think in terms of adaptation only when no simple physico-chemical explanation in terms of the laws of physics can account for the trait under focus. Therefore, one would wonder: what are the criteria to recognize those traits for which “being an adaptation” is not too onerous an explanation ? A simple criterion, indeed, is *complexity*. Traits that are really complex are very possibly adaptations. Their explanation should rely on selection – and precisely, a selection that is cumulative (see below for more precisions on that term).

*Complex adaptations*, in the sense of adaptations that are made of many parts entangled in a way likely to score very high in many complexity measures, are precisely the kind of features which often deserve attention, because they are hard to naturalistically explain; indeed, for Richard Dawkins (1982) their understanding proves the superiority of Darwinism over any other biological theory<sup>5</sup>. It is to be noticed that complexity is still one of the slogans of antievolutionists, especially intelligent design theorists: they take complexity as the mark of some subtle design underlying biological nature. Given that, as I indicated, the idea of natural selection straightforwardly answers any inference from *functions* or *simple adaptations* to a designer, the only strategy left for supporters of a world architect consists in emphasizing the complexity side of design. ID advocates thereby are somehow faithful to Paley's argument from design, even though they shifted the level of complexity: rather than addressing morphological complexity, they hint at microscopic molecular details of metabolic functioning in cells, supposed to display “irreducible complexity” (Behe 1996). This has been rebutted several times by Darwinians (e.g. Weber 1999), and in this paper I will only consider the logics of the argument from design in order to understand the accuracy of the Darwinian answer.

Notice also that natural selection does not only produce complex features. Simple adaptations like the bear's fur are very frequent, but in general there may also be conditions under which natural selection may precisely favor a decrease in complexity (McShea 2005), especially when the cost of complexity in the environments outweighs the benefits provided by it – often there is a correlation between complexity of adaptations and variability or heterogeneity of environments (Godfrey-Smith 1996).

#### 1.5. Unfolding the basic idea of the design arguments.

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<sup>5</sup> At the same time Dawkins was advocating that the gene's eye view is the best account of the pervasiveness of complex adaptations, because it includes cases of social interaction and kin selection; yet this is wholly irrelevant in the present context.



The term “adaptation” covers three distinct things mentioned above, which have distinct relations to natural selection: simple adaptations; complex adaptations; adaptedness (of organisms). In organisms, adaptations are contrived, and this is denoted by at least one sense of the idea of design (i.e., the aspect of “holistic integration”). Moreover, because organisms are sets of contrived adaptations, many of them being themselves complex, clearly many organisms that we see in nature appear as complex entities. This is how design and complexity are tied together, giving rise to an argument from design.

What is roughly at stake seems that *complex* adaptations – and finally, these complex entities that carry them: organisms - are such that an indiscriminate or arbitrary, in a word *random*, action of matter under the laws of nature has *very few chances* to produce them, so that they should have been *designed*. The brand of design arguments insisting on complexity of design, I call it “complexity-as-design argument”. Now that we have, since the advances of mathematical logics in the second half of the 20<sup>th</sup> century, some formal definitions of complexity and randomness, no real formulation of this argument in terms of formal concepts has been given – that is, a formulation of the connection between low probability, randomness, being designed, and complexity.

Basically, the intuitive idea of the complexity-as-design argument is that features like the camera eye of vertebrates, or the radar of bats, or the fine-grained channeling of the lungs, are such that if we considered separately all of their elements, the set of possible arrangements which makes up a lung, or an eye, or all those things, is far smaller than the set of possible arrangements making any other disordered or non-viable structure – not to speak of the organisms that have those features as traits or organs. Picking up randomly one arrangement in this set is very unlikely, therefore, to yield the complex feature we are looking for. This is what I’ll call the complexity-as-design argument.

However, even if organisms don’t possess complex adaptations, the simple fact that their traits are contrived gives rise to another inference to a designer. Contrivances, here, are such that considering separately all the traits, and fixing their values with no expectation regarding the viability of the combination (i.e., fixing it randomly), one could not predict that a contrived system - among all other recombinations of trait values - will be yielded. Therefore, randomly picking an arrangement amongst all the possible arrangements has far more chances to pick up a disordered rather than an ordered – i.e., contrived - arrangement. Kant’s claim above summarizes very well this essential role of low probability : “*the contingency of coinciding with such a concept [of a regular hexagon], which is possible only in reason [in the sense that each side has a same measure prescribed], would seem to [the spectator] so infinitely great*”. Since coincidence is so improbable, there should be a designer. This second kind of argument focuses rather on contrivance than on complexity – it is the “contrivance argument for a designer”, and I will treat both arguments as distinct in what follows.

In the next section, I will use more rigorous concepts of complexity and randomness to formulate those argument and assess its validity.

## **2. Complexity, algorithms, low probability and randomness.**

The bulk of the design argument seems to be the relationship between complexity and randomness. Hence it appears natural to look at theory of complexity and randomness in order to make sense of that. Formally speaking the complexity of a sequence is the length of the smallest algorithm able to produce it (Kolmogoroff and Upensky 1988). It’s a crucial theoretical point, and may allow one to compare the complexity of sequences/ systems, even though it is famously known that computing the complexity of a given sequence is extremely difficult. There are many definitions and measures of complexity (Adami 2001) but the usual computational definition in Kolmogoroff style enables one to also define randomness, which should play a role in the argument.

A definition of randomness can be given in this context as: a random sequence  $x$  is such that no algorithm shorter than the sequence can produce it, the shortest one being the instruction PRINT “ $x$ ” (Chaitin, 1977). This definition captures many aspects of randomness, especially the fact that it is associated with a lack of predictability (the existence of a shorter algorithm means a sort of shortcut, and hence predictability of the digits of the sequence). A crucial consequence is that from such definition one derives the “statistical randomness”, which is the fact that knowing a given digit of the sequence (or a subsequence) cannot allow you to predict anything regarding the next digit (Martin-Löf 1970, for the demonstration).

As we see by comparing these definitions, a relationship between complexity and randomness is built in the formal notions of complexity and randomness elaborated in the framework of computation theory. Although such a relationship may seem strange at first sight, it can make sense intuitively as follows. Precise definitions of complexity, as well as measures of complexity, may be hard to grasp, but one would easily agree, first, that entities made up by a few things (in a very general sense: very few parts, very few rules, very few degrees of freedom, etc.) are simple (i.e. not complex); and, second, that among all things that are *not* simple, the ones we think of as complex display some sense of *order* (in an intuitive sense at least) – accordingly, things made up of many things with no order will be deemed simply chaotic (in an intuitive sense; chaos and randomness strictly speaking are different, though, see Lesne 2001) rather than complex. The computational definitions of complexity and randomness seize these features: the fact that some algorithm should be built in a complex sequence and likely to compress it captures the dimension of order; the fact that the shorter this algorithm, the less complex it is, captures the fact that complexity has to do with the variety/diversity of parts (meaning here the length of the sequence or of the algorithm – these are not much correlated, but clearly, very short sequences will often have very short algorithms).

Thus it makes sense to use a computational approach (which shows a link between complexity and randomness) in order to explicate some arguments from design. The implicit connection I can find between randomness, complexity in formal sense and complexity of a design will be developed below. In all this section, I proceed in a very abstract way. No element from biology is really taken into account, the aim is rather to give the principle underlying what goes on with design arguments. For this reason in what follows I consider very generally an organism as a structured set of parts and subparts, considered very abstractly. Some work would be needed to build a specific biological argument from design in a proper case, by instantiating what will be stated here, but my claim is that, to the extent that the argument from design is meaningful, it relies on what will be sketched here.

First we consider that an organism is a set of parts  $[s_i]$  in a set  $S$ . Those parts have specific relations (be contained in, be involved in a same process, etc.)  $[r_j]$  (relations that can be dyadic triadic, etc.). Some parts may themselves be made of parts but we can consider in the set  $S$  all the subparts, assuming that each part is enough decomposed.

Intuitively there are two approaches to figuring out the claim (P) “ $X$  cannot be here by chance” which is stated in any argument from design.

- It may mean that among all the  $K$  ways to put together the  $s_i$ , if you chose randomly one of them, you will almost never produce  $X$ ;
- It may also mean that if you randomly pick a  $s_i$ , a  $s_j$ , and a  $r_k$ , and then proceed the same way until you have related all parts  $s_j$  (allowing some redundancies in picking some  $s_j$  since the same part in an organism can be present in several relations to several other parts), you have almost no chance to produce  $X$ .

These interpretations are in fact logically equivalent except that the second one specifies conditions on the set of relations; however they are expressed here to provide two intuitively

distinct ways of representing what “here by chance” can mean. Now, which argument would entitle one to conclude to (P) (interpreted in either of the two senses) regarding an organism X? This is the question addressed in this section.

In what follows I start from giving a formal example of the connection between design and low probability. This will illuminate an aspect from the argument from design but will not specifically capture the role of complexity. In a second step, I will focus on the relation between randomness and complexity. The last step will unpack the contrivance-based argument from design, that I distinguished from the complexity-as-design argument above.

*2.1. Cellular automata: a toy example regarding the issue of low probability.*

Cellular automata are very simple deterministic models of natural processes; their simplicity makes them a useful tool to formulate general problems in the simplest way. A cellular automaton C is a formal object, defined in the following way:

There is a set of  $n$  cells  $c_i$ , that can be in 2 possible states. At first step, the states of all cells are given. Then, the state of the cell  $c_i$  at the step  $n+1$  will be defined by the states of its 2 neighboring cells at step  $n$ , according to a fixed rule (for instance: if at least one neighbor is “on”, then let  $c_i$  be “on”). (Notice that the number of neighboring cells can be more than 2, of course; and the possible states of a cell can be also more than 2. In principle, the number of neighbors is  $2k$ , and the number of states is  $m$ , these numbers being determined in advance, and only limited by considering the total length of the automaton. For the sake of simplicity I only consider 2-states cellular automata with 2-neighbours rules).

Now, each initial configuration and each rule defines a specific cellular automaton. There are 8 possibilities for each triplet of cells (the focal cell, and the two adjacent cells), and each triplet can be related to two states of cells, so there are  $2^8$  possible rules (see Fig. 1). Wolfram (1990) famously studied the behavior of all 256 rules, and divided them into 4 behavior classes but this is irrelevant here. The only thing to know is that some of these rules converge to a fixed or periodic state.



*Fig.1. A rule as an application from all possible triplets of cell states to the two possible cell states.*

Just consider one set of cells - each of them in a specific state – called X, in a one-dimensional 100 cells CA. Suppose that we pick out randomly a rule R and an initial configuration T. How probable is it that we arrive at X after having run the automaton with rule R and configuration T? There are 256 rules, and  $2^{100}$  possible initial configurations, so we have one chance on  $256 \cdot 2^{100}$ , which is very low. Any constraint on the initial configurations is not really increasing the chances, since in fact, even 1/256 (i.e., no possibility to chose the initial configuration) is a very weak chance of getting a result<sup>6</sup>. This shows that picking randomly out a way of producing a result is not giving us lots of chances to get the expected result X.

But, as announced, this does not exactly correspond to all arguments from design, since it does not take complexity into account. This speaks mostly about the fact that a specific target cannot be

<sup>6</sup> Actually we can even drop the clause that we focus on states on which an automaton should have converged. We can consider states reachable at some step T (T being a number or an interval) in an automaton ; this even reduces the chances to randomly get the target sequence by picking up a rule and an initial configuration by chance.

reached by chance, if no constraint is given regarding the rules that one considers from the beginning. What it actually parallels is the case of *simple adaptations*. A simple adaptation can be seen as one among a set of trait values – for instance, one colour, among many possible colors, that fits the background on which the organisms live, and therefore allows those organisms to prey unseen or to better escape predators. My toy example of the CA therefore shows that there is a very low probability to reach the best fitted colour, if all production rules are from the beginning possible and equally considered. It is an algorithmic version of a design argument that would go like this: “We see that X has one trait value that fits its environment; but many trait values were possible, so it is very unlikely that this value (e.g. colour) is here by chance – because this value has, a priori, a very low probability.”

Granted, this argument is, as such, not so convincing; one could think of any ways through which indeed the actual trait value is reached through the laws of physics (for instance, think of an effect of the background colour onto the colour of the organism) and here it would very plausible to say: “once we’ll have more knowledge of the physics, what exists will seem far more probable”.

More generally, such a (poor) argument just says that when many  $n$  things such as outcomes from CAs are possible, and no reason is given to expect a priori one rather than the other – i.e. they are equiprobable – then each of them has a probability of  $1/n$  which is very low. This sounds trivial; yet it’s not in fact so trivial once we consider again our CAs. Suppose that CAs were such that, in fact, most of them converge on only two or three sequences<sup>7</sup>. Then, if we have in the world one of these sequences, it’s plausible that it is here because of a chancy pick of one rule – since any rule has in fact  $1/2$  or  $1/3$  chances to yield the desired sequence. In this case the argument about chance in fact does not work. The rules and initial configurations are indeed very numerous, and therefore the probability of getting one of them specifically by a random pick is extremely low, but given that all of them can be partitioned into three sets, each of them converging onto one sequence, the probability of outcome sequence on the basis of random pick is quite high. *Mutatis mutandis*, showing that the laws of physics indeed render the fit between an organism and its background that we have witnessed, expectable, essentially means that we understood the laws of physics as making many states of the world converging onto this simple fit, so that looking for an explanation of the so-improbable event constituted by this particular fit is an ill-formulated question. In any case, the argument from design, if it is to have any force, should be different than this argument of low probability of an event in a large set.

## 2.2 Complexity and the design argument.

We have gotten a hint of what it means to say : (P) “this structure could not be here by chance”; however, the role of complexity is not apparent in the above examples. So let’s consider the organism X as having some degree of complexity. The purpose here, is to show that *increasing* complexity makes it less and less likely to come out with X by chance.

We do not need to focus on X, but on a part of X (say X\*) that is complex. As sketched above, we consider X\* as made up of parts  $s_i$  ( $0 < i < M$ ) which are in relations  $r_j$ . If M is large enough, let’s say higher than 1000, then we can consider that the number of possible dyadic relations is the number of pairs in S (hence  $1000 \cdot 1000$ ), the number of triadic relations is the number of triplets ( $1000^3$ ), etc. X\* is made up of a large number of pairs, triplets, possibly n-ary relations with n being up to 4, 5, or even more than 10, depending on how one defines relations. In any case, if one

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<sup>7</sup> This is not the case, and given that CAs are mathematical objects, it can not be the case that they are otherwise than they are, so this supposition is just a fantasy and not a genuine logical possibility – but it’s helpful to think about it here.

picks up randomly some pairs, and some triplets, etc., in  $S$  – for instance let’s say 100 pairs, 100 triplets, some more  $n$ -ary relations, then there will be less than  $100 / 1000 \cdot 1000 \cdot 1000^3$  chances that one has picked up the set of parts/relations that defines  $X^*$ . The details of the computation here are not significant, given that it’s obvious that the probability of reaching  $X^*$  by such picking up randomly parts / relations is so low.

However, once again the role of complexity is here not apparent. To understand this role, one has to bear in mind the important notion of “compressibility”. A sequence is compressible if there exists an algorithm shorter than its length, which can describe it. For instance, the sequence (0, 2, 4, 6, 8, …, 7800) can be described by the program [0, “add 2”, “if output < 78 repeat”, “if output = 7800, stop”], whose length is very small. In the contrary, incompressible sequences are random sequences (no shorter program exists that allows to describe them).

Abstractly, we can view the combination of  $s_i$  and  $r_j$  – making up  $X^*$  - as a sequence  $\underline{X}$ , each of them being an element in the sequence. Saying that  $X^*$  is complex means that there is a program  $C$  of sequence-length  $C^*$  (the complexity of  $X^*$ ) that yields the sequence  $\underline{X}$  proper to  $X^*$ .

$C^*$  is such that :

$0 \ll C^*$  (since if  $C^*$  is intuitively small we will not speak of complexity, given that in vernacular language “ $x$  is complex” means that “ $x$  has a high complexity value”)

and

$C^* \ll [X^*]$ , where  $[X^*]$  stands for the length of the sequence  $\underline{X}$ .

To say that  $X^*$  could be randomly produced is to say that randomly picking up a sequence, we have a decent chance to pick up precisely the  $C$  that yields  $X^*$ . Suppose that this is true. Now, what happens if we consider organic parts  $X^*$  of *increasingly* higher complexity ? If  $C^*$  increases, then what happens to our ability of randomly finding  $\underline{X}$ , the sequence proper to  $X^*$  ? This precise question tackles the bulk of the design argument regarding complexity. In effect, there is a result in complexity theory that says: (T) “As  $n$  increases, the proportion of length- $n$  sequences that can be described by a program with less complexity (and thus being not maximally random) decreases and the proportion of the truly random sequences increases.” (Anastasios 2008, 25). (T) is involved in the heart of the complexity argument from design, in the following way:

If  $C^*$  increases, then very probably  $[X^*]$  increases. But when the length of a sequence increases, then the amount of sequences of such a length that are compressible decreases compared to the number of incompressible (hence random) sequences. (At the limit, the proportion of  $n$ -length sequences that are random tends to one. )

Now, by definition (because it has a complexity measure)  $\underline{X}$  is compressible.

By picking up a sequence randomly, the chances to get  $\underline{X}$  are by definition smaller than the chances  $x$  to get *a compressible sequence in general* (since  $\underline{X}$  is one among the set of compressible sequences). Given proposition (T), the amount  $S_C$  of compressible sequences tends to be very small as compared to the amount of random sequences  $S_R$ ; hence the amount of compressible sequences  $S_C$  among the overall set of sequences of the same length  $S_x$  is very small. Therefore when  $[X^*]$  increases, the chances to randomly pick up one compressible sequence in this set, measured by  $S_C / S_x$ , tend to be extremely low. Hence the (even smaller) chances of picking up exactly  $\underline{X}$  in the set  $S_x$  of sequences of the same length are almost null after  $[X^*]$  reached some value.

This means that the more  $C^*$  increases (so, the more complex is our part  $X^*$ ), the less likely it is that, by randomly picking up a sequence, we will pick up the sequence  $X$  characteristic of  $X^*$ .

So here : if  $X$  is complex, then it is very unlikely to be here by chance.

However, the argument from design should, on this basis, conclude to: “then  $X$  is here by design”. How does this next step occur ? We have shown that the more  $X$  is complex the less likely it has been randomly produced. We say then that  $X$  can not be here randomly; that is, it can not be here by chance. Now, *pure chance* means the fact that all possible states have about the same probability: therefore, they are equiprobable. There is a slip at this point from the computational sense of randomness, used in this reconstruction of the complexity-as-design argument, and the equiprobability sense of randomness. This second sense is however entailed by the first: if a sequence is random, it means that its elements are equiprobable (statistical randomness), in the sense that considering one position in the sequence, each of its member is equally probable as a fulfiller of this position.

Thus, saying that “ $X$  can’t be here by chance” means that it is not the case that the sequence  $X$  could have been picked up by chance among all possible sequences. So there is something in the nature of  $X$  which makes it the case that it has been picked up, rather than other possible sequences. Hence the notion of producing  $X$  should be relevant to the fact that  $X$  is here. In Kant’s terms, the concept of  $X$  is at the source of the possibility of  $X$ , which means in other words that  $X$  is designed.

We see therefore that via theorem (T) complexity theory allows us to explicate the argument from complex design. The increase in complexity makes it legitimately very difficult to get an organization through any instance of “random choice” (this formulation captures the idea that laws of nature plays in a mode where they don’t tend towards anything, that is, no output has any probabilistic privilege over other outputs). For this reason, one has to think that in case of a very complex trait  $X$ , accounting for its presence should assume in nature an algorithm designed to produce it, since the concept of  $X$  should be what accounts for  $X$ , in other word,  $X$  is produced according to its concept or designed (the “algorithm” is what according to which  $X$  is produced; this precision will be useful later on).

### 2.3. *Argument from design and contrivances.*

There is however another aspect of the argument from design that does not rely on some idea of complexity. Recall Kant’s parallel with the regular hexagon found on the sand (Kant 1790, §62). Kant says, it is very improbable that this hexagon is here by chance - meaning: via the sole effect of the laws of nature, with no concept that would have driven its production. Kant’s argument here is something like: all possible shapes, even shapes with six edges, are indifferent regarding nature itself, so why do we find here a regular hexagon rather than any of the other 6-edged shapes ? There should be a reason for that, in the sense of the concept of the regular hexagon having been put at the source of the production of the shape.

But interestingly, a hexagon is not so complex. So the rationale for argument from design here, should be a bit different than in the previous case, if we intend to shed light on it through the viewpoint of a formal theory. What is alluded to here by Kant seems to be another variant of the argument from design, centered on the idea of contrivances rather than complexity. In the regular hexagon, all edges seem to fit all other edges (in the sense that they have the same length); correspondingly, the intuitive idea of contrivance in biology is that parts are fitted to one another, and

all of them are like contrived to a common purpose (which is survival and/or reproduction). The contrivance-centered argument from design, here, would state something like:

“X shows so much contrivances that it could not be here by chance.”

How to interpret this relationship between contrivance and chance ? To address this question, I recall an old characterization of organisms due to Cuvier, that has been very influential until now, because it captures something crucial for an organism – something that indeed could be called “the design of the organism” (Huneman 2014a). For Cuvier, all parts in an organism are related to each other in a way that makes possible the existence of the organism in its milieu; he calls it the “*principle of the conditions of existence*”. It has been so important that in the 6<sup>th</sup> chapter of the *Origin*, Darwin sees the “principle of condition of existence” as one of the two laws of biology (together with the “law of unity of plan” due to Geoffroy Saint Hilaire).

Cuvier’s principle indeed captures the already mentioned fact that organisms are contrived; this principle indeed has as a corollary the fact that each part of the organism is such that it fits the other parts. Cuvier famously argued that when he finds the tooth of an animal of an unknown species, a reasoning can allow him to reconstruct the other teeth: as a carnivore, since the animal used this tooth to cut the prey, it should have this other sort of tooth to chew it, etc. Then it needs also a maxillary bone of a specific size to hang this jaw, and then appropriate muscles to support and move it; therefore it also needs claws to kill preys, hands and limbs to reach them, and then it also needs legs to run and catch preys, eyes to detect them, and so on. The ‘principle of conditions of existence’ therefore entails a “*principle of correlation of parts*”, whose impressive consequence is the fact that Cuvier was able to reconstruct organisms of extinct species entirely from a fossil bone, as he shows in the *Discours sur les ossements fossiles des quadrupèdes* (Cuvier 1812). This second principle – “Cuvier’s dictum”, as I call it here – provides us with a criterion to recognize organisms: in these objects, the knowledge of parts allows us to *predict* other parts. Cuvier’s dictum is a criterion to detect contrivances in nature.

From this on, a second form of the argument from design can be understood and justified in a formal way. Remember that randomness of a sequence means the inexistence of an algorithm shorter than the sequence such that it can yield the sequence. This definition also entailed statistical randomness, i.e. no digit of the sequence, or no subsequence, is predictive of the next digit. Suppose now that we have an entity X, characterized in terms of parts and relations like in the previous subsection. Suppose also that X is random, in the sense that it is made of parts and relations randomly picked up one after the other with no rule intended to make it up – in a set S of parts as stated in 1.2. In this case, because of this randomness (as lack of a rule or a short algorithm), X displays statistical randomness; namely, knowing a part in the sequence of X is not likely to inform us about the next part. But this is wholly contrary to Cuvier’s dictum, according to which parts are in principle informative about other parts in an organism. Therefore, X is not an organism. Conversely, if X is an organism, and then contrived as an organism is, then X is *not* randomly produced. The connection between computational randomness and statistical randomness in complexity theory is what allows us to justify this second version of the argument from design that does not consider complexity but simply contrivances. Then the last step of this argument, like I the previous version, relies on the inference from non-chance to “the concept of X is relevant upon its presence “and therefore “X is designed.”

### **3. The Darwinian solution: selection, cumulative selection and optimality theory.**

The previous section sketched a formal skeleton of the complexity-as-design argument, as well as the contrivance-to-design argument, which are the two faces of the argument from design as it has

traditionally been used to bridge biology and natural theology – from Cicero to Dembski (1998), Behe and current-day ID authors.

In 2.1 I hinted at how Darwinian biological evolution solves a weak form of the argument from design based on simple adaptations and fit with environment. Gardner (2009) shows how Grafen's Formal Darwinism provides equivalences between a formulation of evolution in terms of gene dynamics and a formulation of evolution (often used by behavioural ecology) in terms of organisms as optimizing agents (Huneman 2014a) that allow a general view in which organisms can indeed be legitimately seen as designed to maximize their "inclusive fitness" (Hamilton 1963).

In what follows I will explain how the *complexity-as-design* argument is solved through the Darwinian idea of natural selection, by focusing on the link between cumulative selection and complexity. Through this argument, it will appear that a specific form of argument from design can be used within the Darwinian framework and expand the idea advanced by Williams (1992) that complexity is the hallmark of adaptation and then selection.

### 3.1. How Darwinian selection (dis)solves the argument from (complex) design.

Most generally, in Darwin's conception, the process of natural selection bypasses chance by retaining sequences which are more complex than other realized arrangements, and therefore somehow at any point of the process restraining the next random choice to some of those retained sequences - and then repeating the operation again and again. How to more precisely make sense of that, given the previous section? Remember that the bulk of the complexity-as-design argument relies on the fact that *increasing* complexity makes it less and less likely to randomly produce the complex item. Hence, as it is said, when the complexity measure is low, the argument does not really hold, and this matters much in the Darwinian solution to the complexity-as-design argument.

Given  $X^*$ , that has a high complexity measure  $C^*$ , what does the Darwinian approach indeed say? The question of whether the sequence  $X$  could randomly arise from nothing is not at all relevant here. Because it is supposed to have evolved by natural selection and that selection targets small variations in a population of variants, we can think of  $X^*$  as evolving from an anterior state  $X'$  of lower complexity  $C^{*'} < C^*$ . The question of the arising of  $X^*$  therefore concerns how to produce a sequence of complexity  $C^*$  from a sequence of complexity  $C^{*'}$ . According to the way natural selection proceeds, the first step is the production of variants, and the second step is about retaining some variants that are fitter (Mayr 1984) – notice that in the present context the fit is defined by complexity since one intends to explain the arising of high levels of complexity.

In this case, assuming a population of sequences of complexity  $C^{*'}$ , one can safely bet that among several variations on the sequence  $X'$  characteristic of  $X'$ , some of them will be of higher complexity than  $C^{*'}$ . There is no argument saying that randomly changing the nature and the length of the sequence  $X'$  will produce a compressible sequence with only a low probability, since  $X'$  is already a compressible sequence. So probably some variants will be compressible and some of them will have a higher complexity than  $C^{*'}$ . Therefore, provided that many variants can be produced, the two steps of natural selection will very probably produce some sequences of complexity higher than  $C^{*'}$ ; if this is still lower than  $C^*$ , the reasoning can be repeated one more step, and so on, until one reaches a sequence of complexity  $C^*$ , which is what we wanted to explain. Natural selection bypasses the complexity-as-design argument because it breaks the high complexity score into subcomplexity levels, and restricts the issue of complexity-producing to a mere random increase in complexity.

This restriction procedure is exactly what Darwin is doing when he shows that elementary light detectors in some species may have displayed some variations, some of them being incrementally beneficial and having been retained, so that in the next step the only variations to be considered are amongst those beneficial ones, and so on. The procedure here formally amounts to restricting the



complexity range in the existing variations, so that we do not any more have as extremes a  $C^\circ$ -complexity feature very low and a  $C^*$ -complexity feature very high (such that  $C^\circ \ll C^*$ ) - and therefore the complexity-as-design argument cannot hold.

Design arguments concludes traditionally that since X cannot be here by chance, there should be an intention at its source, meaning that the production of X should have been guided by an intention to produce X. In Kantian terms, there is a concept that lies at the source of the possibility of X; otherwise X would be so improbable that it would finally be impossible. But according to Darwin, something else than intention (i.e. the intentional choice of some algorithm *because* it produces the expected X) is able to account for X as a complex feature.

### 3.2. *Complex adaptations and cumulative selection.*

The above reasoning makes it clear that complex features should evolve by incremental selected steps, which is labeled “cumulative selection”. This is a specific form of selection. Granted, because selection works with small variations, it is traditionally thought as *gradual*. In classical Modern Synthesis thinking, the core view is that: “Natural selection, acting on the heritable variation provided by the mutations and recombination of a Mendelian genetic constitution, is the main agency of biological evolution” (Huxley in a 1951 letter to Mayr). The Mendelian constitution is an inheritance system made up by Mendelian genes; the “beneficial” mutations of these genes should be in general small because large mutations have lots of chances to disturb organisms, since those are in general already finely tuned systems whose parts are contrived in a way such that too much modifying one part will alter the whole (Fisher 1930). Hence variations that can be retained by selection are small, and therefore the evolution by natural selection is gradual. Think of evolving a new fur colour for a species that lives in an environment whose average colour have been altered by global change (an example parallel to the case of the peppered moth): if organisms’ colors have to evolve from red to blue, one will witness an evolution going through violet, indigo, etc., until reaching blue.

This gradualism can be seen as “cumulative”, but there is another sense of cumulative that is more relevant to complex adaptation. In my example, suppose that each colour is conditioned by one mutated allele; then gradual selection does not *cumulate* various results of selection, but somehow *goes through* them, reaching the final allele after having crossed all the others. Consider now a trait X such as a foraging behavior, which would be conditioned by a large amount of genes  $[g_i]$  (as is the case with almost all extant traits). Given that evolution by natural selection proceeds by changing gene frequencies<sup>8</sup>, evolving the trait X should evolve by natural selection all the  $g_i$ , which add up eventually in coding<sup>9</sup> for trait X. Here, the process starts by fixing one  $g_i$ , then another  $g_j$ , and so on: it is cumulative in the sense of successively retaining selected genes. (The genetic wording, here, is not compulsory, the same thing could also be said in phenotypic terms, but in this way it’s easier to formulate the difference between gradual and cumulative.) Building a complex feature via natural selection goes through steps of increasing complexity that are each selected in turn, as we saw. Giving an evolutionary process of a particular amount of steps, the building of a step n complexity trait from a step n-1 complexity trait could be seen as the progressive addition of complexity steps, and each of the steps could be seen as a retained trait of some complexity. The construction of the mammals’ camera eye simulated by Nilsson and Pelger in order to implement Darwin’s reasoning instantiates such a process of cumulative selection, where at some steps various features proper to the eye are constructed and retained.

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<sup>8</sup> This statement is neutral regarding whether changing frequencies constitutes adaptive evolution, is adaptive evolution, or just indicates it.

<sup>9</sup> Here too, the controversies over the legitimacy of the « information » or « code » talk regarding genes is left aside ; no commitment needed to the substantial claims that sometimes are supporting such talk.

Two consequences should be noticed here, regarding the tie between complexity and cumulative selection.

First, consider a complex trait and assume that its genetic make-up involves many alleles  $g_i$ . A high complexity value would involve many contrived alleles (even though the reverse is not true : a simple trait such as the size involves many alleles). In population genetics, one can compute the expectation that, when two alleles occur in a population, one goes to fixation under drift (Gillespie 2004). If the population is large enough, the chances that drift drives the less fit allele to fixation are quite low. Now, the chances that X is here by chance mean, in the context of population genetics - which is the heart of the Modern Synthesis - the chances that *all the*  $g_i$  are here because of drift. This is therefore the product of the chances that each of the alleles  $g_i$  is there because of drift, which is indeed very low - even when the population size N is not too large (since it's a product of quite low probabilities, whose denominator is  $N^k$ , k being the amount of alleles involved in the genetic make up of the trait - that can be very high even though N is not too large). Hence, the whole trait being here because of drift is very improbable, which justifies seeing the trait rather as a result of cumulative selection. This sounds like a complexity-as-design argument, devised in the context of population genetics. Williams' criterion - "X is an adaptation if X is complex enough" - is legitimized from the viewpoint of population genetics. So when one sees a complex trait, in our modern perspective, one sees a biological phenotype whose genetic make-up is very unlikely to be here by drift and then calls for a selective explanation.

The second point concerns the well known fact that now many evolutionary biologists challenge the Modern Synthesis viewpoint. Some call for an "Extended Synthesis", as stated in the eponymous manifesto (Müller and Pigliucci 2011), which synthesizes many of these arguments coming from various disciplines. The abovementioned tie between cumulative selection and complexity seems therefore less obvious than it seemed to the orthodox Darwinians and is exposed above, as I'll quickly indicate.

Actually, notwithstanding the huge variety of arguments that come into play when challenging the Modern Synthesis (e.g. some concern development, others concern inheritance, others are about the tempo of evolution, etc.), one key point concerns the respective explanatory roles of selection and variation. The Modern Synthesis assumes a large amount of variation, random in some sense (Merlin 2010), in which selective pressures constantly favor higher fitness variants in terms of reproductive success. However, if the variation is quite sparse, or is intrinsically directed upon beneficial variants, then the explanatory force of selection would be much lowered. Suppose for instance that regarding our complex trait X all the alleles  $g_i$  are available in the initial or later variation (e.g. they could be alleles at various loci (1... i... n) and distant from only few mutations from the initial alleles  $g_i^0$  at these loci found in the population). In this case, selection may indeed yield the complex trait by producing the make-up [ $g_i$ ] after a gradual and cumulative process. But imagine now that X is made up of several gene-complexes, which are themselves complex, and consider that only a few gene-complexes are likely to appear as variants. In this case, explaining complexity will not be content with cumulative selection, because one wants to understand the arising of these possible complex networks that appear in several variants and that will enter into the composition of the complex trait under focus.

Therefore, the question regarding the scope and the legitimacy of understanding the whole of biological evolution through the perspective of the Modern Synthesis impinges upon our view of the relation between selection and complexity - which, from an orthodox Darwinian viewpoint, could be summarized in the phrase: "complex organization appeals to a cumulative selection explanation".

## Conclusion.

Contemporary definitions of complexity and randomness allow one to make sense of the first step of the classical design argument, namely the inference from some complex or contrived structure to a very low probability of resulting from “random choice”, and therefore to the high probability of an underlying algorithm. This algorithm has often been presented as the “designer”. The Darwinian solution of the problem of design is a more satisfactory option. Its resources can be understood in relation to an explication of the bulk of the complexity-as-design in terms of computational theory. It relies on cumulative selection, which somehow “breaks” high levels of complexity into small complexity steps that can be gradually crossed. The Modern Synthesis seems sometimes (Müller and Pigliucci 2011) to have lost sight of organisms and their design, but it provided a way to understand the necessity of cumulative selection, and justifies the fact that complexity can confidently be seen as a sign of something that is not here by chance (interpreted as random drift).

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