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Introduction: fixed forms, flexible natures

For Aristotle, living beings are complex composites of matter and form, where form is to be understood functionally, and not merely as shape, as a specific combination of soul-capacities that characterizes the kind of living being in question. It is a commonplace in Aristotelian scholarship that both these forms of living beings and the enmattered animal species to which they give rise are "fixed". Forms are "fixed" in the sense that they—without being eternal themselves—are *replicated eternally* through sexual reproduction from father to offspring: the offspring receives a "potential for form" that is formally (but not numerically) *identical* to the form its father possesses in actuality.[1] Since this potential for form is for the most part—that is, if nothing greater impedes—realized in the same way, and since the cosmos is eternal in time, Aristotle believes that there is a continuous generation—and corruption—of organisms that are one in form and that instantiate the same range of animal species.[2] Within these confines, there is no room for a transformation of species.

In seeming contradiction with this fixity of species, however, Aristotle's biological works often stress the flexibility of nature during embryogenesis and the later development of animals. Aristotle typically describes the process of the actualization of a potential for form into an actual animal in terms of "formal natures" "making" or "producing" the animal. This formal nature instantiates the animal's efficient, formal, and final cause (which is identical to its soul), and following the craft-model already employed by Plato, Aristotle personifies this internal principle as acting for the sake of something, while following a certain *logos* or "guideline" for building (see, e.g., *PA* I 1, 641a23-28; *DA* II 1, 412a19-21 and *GA* IV 4, 770b17).[3] Given the unchangeability of animal species, one would expect these "guidelines", or "definitions of the animal's substantial being," to be rather strict and precise, but instead Aristotle suggests that they are underdetermined. Instead of this being specified by the animal's *logos*, Aristotle claims that it is somehow "up to" formal natures to determine which parts to produce for the performance of a certain function, *how many* of those parts they should make, and *where* in the animal body they should place them. Evidently, even though the starting points (i.e., the potentials for form) and end points (i.e., the fully developed animals of a given species) of animal generation are "fixed" and "permanent" features of the world, the individual actions of the formal natures through which this process is carried out are not similarly pre-determined.

My purposes in this paper are, first, to delineate the range of flexibility Aristotle believes natures actually have in their design of animals, and second, to draw out some of the implications this has for our understanding of Aristotle's account of embryology and his theory of natural teleology. I will argue that Aristotle's tendency to think of the activities of formal natures in the production of animals *as if* performed by tinkering craftsmen shows that for him, the structure and functionality animals have is as much a result of the teleology embedded in their forms as it is of the goal-directed actions performed by their formal nature in realizing those forms. This indicates that at least *at the level of embryogenesis*, Aristotle does allow for something like a transformation of species[4] and that his view of development is epigenetic in the true sense of the term. That is, the "guidelines" for building with which nature works do not predetermine in advance all the changes that need to be made, but rather leave room for nature to make adjustments to animal design "on the fly," as the development proceeds. For his theory of natural teleology this means that the underlying physiology must be rather complex and flexible: the potentials for form that guide the realization of those species are dynamic, rather than blind, automated self-regulating principles, as they are shown to be capable of responding to "unexpected" changes in circumstances.[5]

1. The problem of animal design in Aristotle's biology

In his famous exhortation to the study of philosophy in the *Parts of Animals*, Aristotle argues that we should not look down on the study of animals that are not pleasing to perception, because "the nature that crafted them (ἡ δημιουργήσασα φύσις) likewise provides extraordinary pleasures to those who are able to know their causes and are by nature philosophers (*PA* I 5, 645a7-10)." He continues by saying that it would be unreasonable and absurd that, "if we enjoy studying likenesses of animals on the ground that we are at the same time studying the art that crafted them, such as painting or sculpture, we would not be even more fond of the study of things constituted by nature, at least when we can observe their causes (645a11-15)." Aristotle's point here is that it helps to think of animals as being no less the result of a kind of craftsmanship as are their likenesses in paint or stone, and that therefore the study of their causes should provide similar pleasures to those who are philosophically minded.

This depiction of nature as a craftsman is, as I indicated in the introduction, common in Aristotle's biological works, and it often merely serves the purpose of elucidating obscure organic processes, such as embryogenesis in the *Generation of Animals*. For Aristotle, the processes of artificial production and natural generation are similar in that they both involve replications of form in matter through the operation of an efficient cause, and both take place for the sake of creating an

organized, functioning whole.[6] Also, in both processes, the efficient cause starts out as operating from the outside, but in natural generation it ultimately becomes internal to the generative process as the animal's soul. Thus, when explaining why embryogenesis and birth must take place in the female, Aristotle likens the male semen to a carpenter and a potter, who must keep in close contact to their respective materials, and to an architect, who is "in the building it makes" (GA I 22, 730a32-b8). In those male animals that do not emit semen, "nature resembles those who model clay rather than carpenters", because it does not shape the material with tools, but with its own hands (730b8-32; cf. PA II 9, 654b27-32). Once the heart is present, the remaining formation of the embryo takes place through the actions of the soul, which makes use of heat and cold as its tools (GA II 1, 734b20-735a29; II 4, 740b25-741a4; and II 6, 743a36-b5) and proceeds in a manner resembling painters (GA II 6, 743b18-25):

> The upper half of the body, then, is first marked out in the order of development; as time goes on the lower also reaches its full size in the blooded animals. All the parts are first marked out in their outlines and acquire later on their color and softness or hardness, exactly as if nature were a painter producing a work of art (ἀτεχνῶς ὥσπερ ἂν ὑπὸ ζωγράφου τῆς φύσεως δημιουργούμενα), for painters, too, first sketch in (ὑπογράψαντες) the animal with lines and only after that put in the colors.[7]

These comparisons help to visualize the process of reproduction, and are compatible with a non-intentional model of teleology. At least within the context of the *Generation of Animals*, we never see these natural efficient causes waver or deliberate about how best to produce an animal or its parts. Just as expert craftsmen, formal natures automatically "know" what to do and in what order to perform each of their actions (cf. GA I 23, 731a25 and the analogy of nature to a good housekeeper in II 6, 744b11-27).[8]

However, not all of Aristotle's depictions of natures as craftsmen are as innocent as these. Especially in the *Parts of Animals*, Aristotle drops the comparisons and turns nature itself into a craftsman who makes choices, takes away or adds parts, and wishes to do things. It is here that we find the animal design to be in part "up to" nature, rather than being completely determined by the animal's substantial being. The purpose of this imagery, I submit, is no longer didactic, but explanatory: when trying to explain why certain parts or their differentiations belong to the kinds of animals they do, thinking about formal natures as tinkering craftsmen—often embedded in the form of teleological principles such as "nature does nothing in vain"—becomes an important heuristic strategy for Aristotle for the discovery of causes. Where other methods fail to reveal the cause of the presence,

absence, or differentiation of a part, Aristotle appeals to a hypothetical moment in time at which a nature first designed the animal (in a manner resembling the "first creation" of human beings in Plato's *Timaeus*).[9] By comparing the features an animal "should" have had, given its substantial being, to the features the animal in fact can be observed to have, Aristotle discovers a design problem *and* then explains the animal's actual features as nature's teleological solution to that problem. The images of crafting natures as used in the *Parts of Animals* are thus remnants of thought experiments (that combine forms of reasoning very similar to adaptive thinking and reverse engineering) Aristotle engaged in while attempting to find explanations of anomalies in animals, but they also add a level of complexity and flexibility to his theory of natural teleology: not everything that is good in the world of natural phenomena derives from an in itself not further explicable, predetermined good embedded in forms.

In the remainder, I provide support for these claims by discussing three kinds of cases in which Aristotle describes formal natures as deviating from the "original design" or the "instructions" in the animal's form, consisting in (1) the removal of parts; (2) the re-use of already existing parts for a second function; and (3) the production of "luxury" features (such as hairs, horns, and eyebrows) from materially necessitated residues. Using these cases as a starting point, I will then, in sections 2 and 3, lay out the parameters for the actions of formal natures, first the ones that are qualified as being "necessary" for it, and then the actions that are qualified as "best" or as "for the better".[10]

Case 1: removing parts

The clearest case in which Aristotle claims formal natures deviate from the original animal design pertains to "paradoxical" absences of parts. The absence of a part is paradoxical when one has reason to expect that part to be present in the animal in question on the grounds that it can be observed to be present in either all the members of the animal's wider kind, or in many or all closely related animals (for instance, fish—which are swimmers by definition—all have fins, but serpentine fish do not; monkeys have tails, but humans—who are in many respects similar to these blooded land-dwellers—do not). Only if the part belongs (or reasonably could be expected to belong) to the animal's original design, Aristotle tries to explain its absence, and he does so by appealing to the teleological principle that "nature does nothing in vain, but always from among the possibilities does what is best for each being".[11] The principle is an empirical hypothesis about the goal-directed actions of formal natures in the generation of animals: seeing that for the most part animals are not equipped with useless or non-functioning parts, we may infer that this applies to all the works of nature and posit that nature *never* produces anything in vain (see *IA*

2, 704b12-15).[12] Such a general rule of nature then helps to generate a thought experiment: imagine the missing part to be present, and "see" if you can detect some other feature of the animal that would interfere with its functionality or that would make its presence redundant. If there is no such interfering part, the now missing part must be absent for non-teleological reasons: it must be due to a lack of constitutive materials in that animal, which is a material constraint.[13] If there is such an interfering part, however, it must be the cause for why the now missing part is in fact absent: the animal's formal nature "decided" not to produce (or even: to take away) that part on the grounds that its presence would have been in vain in this particular kind of animal.

Let me quote one of my favorite examples (*IA* 8, 708a9-20):

> In snakes the cause of why they are footless is, both, that nature does nothing in vain, but always from among the possibilities, [does] what is best for each thing, preserving the proper substantial being of each and its essence; and, in addition, that which we stated before, namely that no blooded animal can move itself at more than four points. For from these [two principles] it is evident that of the blooded animals whose length is out of proportion to the rest of the nature of their body, like snakes, none of them possibly can have limbs. For they cannot have more than four feet (since in that case they would be bloodless), and *if they had two feet or four they would be almost completely immobile*: so slow and useless would their movement necessarily be.

Observation shows that all blooded animals that live on land have four feet: they share to a certain extent the same form, and their design can therefore be expected to share certain co-extensive features like the possession of a maximum of four feet. The snake, however, possesses all the typical properties that belong to blooded land-dwellers, except for feet. Aristotle explains this absence by pointing out that the presence of four feet in snakes *would have been* in vain, on account of the snake's disproportionate dimensions (and giving more than four feet is impossible, as this would violate the substantial being of blooded animals). A quick thought experiment reveals that no blooded animal whose length is out of proportion to the rest of their body would be able to move swiftly with either two or four feet, and in order to remedy that design problem, nature "decided" not to produce feet in such animals. With this information, it would then be possible to formulate a scientific explanation that does not appeal to any conscious intentionality in nature.[15]

In a few cases, Aristotle even suggests that formal natures actively "take away" features in the production of animals, again because their presence would be in vain. This is, for instance, how Aristotle explains the absence of sideways jaw

motions in fish, birds, and egg-laying four-footed animals (*PA* IV 11, 691a27-b4):

> Since the head is divided in two, the upper part and the lower, mankind and the live-bearing, four-footed animals move their jaws up, down, and sideways, while fish, birds, and egg-laying four-footed animals only move them up and down. That is because up-and-down movement is useful for biting and cutting, while sideways movement is useful for grinding. Therefore for those that have grinding teeth, sideways motion is useful, but for those that do not, it is not useful at all, *which is why it is taken away* (ἀφῄρηται) *from all such animals*; for nature produces nothing superfluous.

Apparently, the "proto-typical" way in which jaws are produced in animals (for the sake of aiding nutrition) allows them to move up and down as well as sideways. However, in those that lack grinding teeth, the sideways motion would be in vain (just imagine its presence!), which is why nature takes it away (cf. *PA* IV 10, 689b21-5; *Cael* II 8, 290a29-35; *HA* II 17, 508a8-11; and Pl. *Ti* 33d-34a).

In both examples, the absence of a part is explained as an improvement of the design implied by the animal's form: blindly following the instructions in the definition of the substantial being would lead to animals with improperly functioning or vain parts, but fortunately, "nature does nothing in vain".

Case 2: reusing parts

A second case in which Aristotle claims formal natures make adjustments to the original animal design involves the "reuse" of an already existing part for a second function. Typically, natures produce one (set of) part(s) for the sake of realizing each of the functions that are specified by the definition of the substantial being (I return to this "rule" below in section 3), and each function has its own proper realizing part. For instance, if the animal is to be a flyer, it receives wings (and not some other part), because wings are the necessary prerequisites for the realization of the function of flying, and so natures produce wings in all birds (*PA* IV 12, 693b6-14), even if not all birds ever engage in flight (693b28-694a9). In a few cases, however, Aristotle believes that the function specified by the animal's form cannot be realized in the usual way: its proper part cannot be produced at all or cannot be produced in a way that makes it suitable for the function in question, and natures will have to improvise and make use of some other part that is already available in the animal to make the performance of that function possible. Aristotle emphasizes that the parts that are being "reused" by nature did not come to be for the sake of that second function: instead, they came to be for the sake of performing some other function (which is their primary and

proper function), but since they are present *and* possess the right kind of material potentials, nature can easily adopt or modify them for the sake of allowing them to perform a second function. Aristotle describes the actions of nature in these cases as making use of a part for another use, where the verb for using bears connotations of misuse or additional use (cf. *Cael.* I 3, 270b24).[16]

A nice example of such a reused part is the elephant's trunk.[17] In a long passage (*PA* II 16, 658b32-659a36), Aristotle first explains why elephants have the specific nose they have. Elephants have a nose in virtue of being a breather of air (that is, noses are a necessary prerequisite for the performance of the necessary function of cooling), but they have the *specific, long* nose they have because they need an organ for breathing air while being in the water looking for nourishment: long noses function for elephants like snorkels do for human divers (659a6-12). However, in order for trunks to be so long, they have to be—of conditional necessity—soft and flexible, and Aristotle goes on to explain how nature makes use of these material potentials of the trunk in order to *make up* for the uselessness of their feet for grasping food (659a20-30; 34-6):

> Since [the trunk] is such [i.e., soft and flexible], nature, as it is used to, uses the same parts for several things (ἡ φύσις παρακαταχρῆται, καθάπερ εἴωθεν, ἐπὶ πλείονα τοῖς αὐτοῖς μορίοις), [here using] it in place of the use of front feet. For four-footed animals with many toes have front feet in place of hands, not merely for the sake of supporting their weight. And the elephants are members of this group; that is, they have feet that are neither cloven- nor solid-hoofed. But since the size and weight of their body are great, their feet are only for the sake of support, and because of their slowness and their natural unsuitability for bending, they are useless for anything else… And the use of its feet having been taken away, nature, as we said, also makes use of this part *for the service that would have been provided by the feet.*

Typically, four-footed animals with many toes have feet that are capable of providing both support for their bodies and means to transport food to their mouths: the form "many-toed four-footer" is "normally" realized by giving these animals four supporting, but bendable feet. However, in elephants, this use of feet is taken away, and so their natures have to deviate from the original design by assigning a second function to the elephant's trunk, but without having to change any of its features. Although physically, the design of the elephant has not changed, natures had to move the function of grasping food to the trunk, a function which was "supposed to be" performed by its feet.

In cases like this, nature still realizes all the functions specified by the definition of the substantial being of the animal, but, because of the design-problems that

only become clear during the animal's production process, it has to do so in an "unexpected" way.[18]

Case 3: adding "bonus features"

A third case in which formal natures adjust an animal's original design involves the use of extra materials for which there are, so to speak, no instructions in the definition of the substantial being of the animal. The teleological processes involved in the realization of the animal's potential for form sometimes produce—accidentally and of material necessity—flows of residues or even entire structures. And even though these materials or structures are thus not themselves an immediate product of the operation of teleology (their coming to be is not conditionally necessitated for the sake of realizing functions specified by the animal's form), formal natures can use them "for the better" by turning them into parts that increase the well-being of the animal, instead of just discarding them from the body. Once co-opted by the formal natures, these parts become beneficial "bonus features" added to the animal's original design: hypothetically speaking, the animal could have done without them, but with their presence, it is better off.[19]

Eyebrows and eyelashes are such "added" features (*PA* II 15, 658b14-25):

> The eyebrows and eyelashes are both for protection… The eyelids are at the ends of small blood vessels; for where the skin terminates, the small blood vessels also reach their limit. So because the moist secretions oozing are bodily, it is necessary that—unless some function of nature stops it with a view to another use (ἂν μή τι τῆς φύσεως ἔργον ἐμποδίσῃ πρὸς ἄλλην χρῆσιν)—even owing to a cause such as this, hair from necessity comes to be in these locations.

As Aristotle indicates, the structures that form eyebrows and eyelashes come to be of material necessity—a process that is not initiated by a formal nature, but also *not stopped* by it. Nature allows the growth of eyebrows and eyelashes, because once present, these structures—because of their hard and earthen nature and because of the location where they of necessity appear—serve the function of protection. In other cases, nature does stop the flow of material, but only to redirect it to other parts in the body, where it uses it for the production of beneficial parts (*PA* III 2 663b22-35):

> But we must say what the character of the necessary nature is, and, how nature according to the account makes use of things present of necessity for the sake of something… For the residual surplus of this sort

> of [earthen] body, being present in the larger of the animals, is used by nature for protection and advantage (ἐπὶ βοήθειαν καὶ τὸ συμφέρον καταχρῆται ἡ φύσις), and the surplus, which flows of necessity to the upper region, in some cases it *distributes* (ἀπένειμε) to teeth and tusks, in other cases to horns.

Both the careful teleological language in these examples ("for" instead of the more technical "for the sake of") and the reference to material necessity in the coming to be of these features are typical characteristics of the "bonus features" in Aristotle's biology. They are never the necessary prerequisites for the performance of necessary functions as specified by the definition of the substantial being of the animal. Instead, they assist other parts in performing their functions, such as kidneys helping the bladder to collect residue (*PA* III 7, 670b23-7), or perform functions that appear to be non-necessary for the animal to reproduce or survive, such as horns providing protection to the male deer that have them (*PA* III 1, 661b28-662a2). Their functions are therefore subsidiary or luxury, and the parts themselves are often simply referred to as being "for the better".

The availability of materially necessitated residues or structures in these cases thus provide "extra" possibilities for natures to produce features that increase the animal's well being and thereby improve them, even though none of these features were part of the original design.

In sum, the development of an animal consists for Aristotle in the actualization of an internal, pre-existing potential for form, transmitted by the father into the female menses and brought to completion through the animal's formal nature. It is this potential for form that encodes the animal's development, and that guides—*but not completely predetermines*—the actions of the formal nature during the different stages of animal development. The picture of the actions of formal natures that arises from the three cases discussed above is that formal natures always act in accordance with the specifications in the definition of the substantial being of the animal they are producing, unless during the production process this turns out not to be beneficial or possible, and that they improve the design of an animal *if this is possible* due to the availability of extra materials. In the sections below, I further specify the parameters for the actions of the formal nature within which these "epigenetic" adjustments take place.

2. Constraints on formal natures: doing the necessary

When Aristotle qualifies an action as being necessary for a formal nature to perform, that typically means that the action is necessary *given* the substantial being of the animal that is being brought into being. Without the realization

of the functions and other features that are specified in the definition of the substantial being of the animal, the animal in question cannot exist or be the kind of animal it is. Formal natures therefore *have to* produce the necessary prerequisites for animals to survive and to have the identity they have (cf. *PA* I 1, 640a33-35); it is part of the teleology of nature that formal natures never fall short in producing those necessities (see *DA* III 9, 432b21-6).

Unfortunately, Aristotle is not very explicit about what kinds and how many of those functions and features exactly are included in the definition of an animal's substantial being. At a minimum, as has already been suggested by Gotthelf and Code,[20] these specifications include (1) the vital and essential soul functions as specified by the relevant differentiae[21] of the animal, and sometimes specific organic parts themselves;[22] (2) the sizes and dimensions of animals;[23] and (3) the bloodedness or bloodlessness of an animal.[24] It is plausible that the definition also specifies (4) the ratio of the elemental blend constitutive of the animal's material nature. Below, I discuss the implications these four kinds of specifications have for the actions of the formal natures, indicating both what actions are necessary for them to perform and (less so) what actions are impossible. Together, these constraints on the actions of the formal natures exhibit the level of predeterminism in Aristotle's embryology and the extent to which teleology is already embedded in the forms of animals.

The first category of features listed in the definition of the substantial being of the animal, that is, the vital and essential functions to be performed by the animal in question, provides stringent guidelines for what parts formal natures must make. In order to realize the animal's form, formal natures must produce (a) those parts that are explicitly mentioned in the definition of the substantial being as well as (b) the parts that are the *necessary prerequisites* for the realization of the vital and essential functions as specified by the relevant differentiae in that definition. For instance, the definition of human beings will include "is lunged" and "is able to see", which means that they must have lungs and eyes, the proper parts for the realization of vision (*GA* V 1, 778a29-b19). Natures cannot produce humans without either of these parts, because in that case humans would *immediately* fail to reach their natural ends (cf. *GA* IV 4, 771a11-14).
In order for us to reconstruct whether a part is such a necessary prerequisite, Aristotle suggests we look at its distribution among animals that all perform the function associated with that part: observation shows that there may well be several parts associated with the performance of the same function, but only the part that is present in *all animals* that perform it is necessary; the other parts must be subsidiary. For instance, ducts for semen and testes both play a role in male sexual reproduction, but whereas ducts for semen are present in all males that reproduce sexually, testes are not (*GA* I 4, 717a11-31):

> Now if nature does everything either because it is necessary, or because it is better (εἰ δὴ πᾶν ἡ φύσις ἢ διὰ τὸ ἀναγκαῖον ποιεῖ ἢ διὰ τὸ βέλτιον), this part [i.e., testes], too, must be because of one or the other. That it is not necessary for generation is evident: for it would be present in all that generate, but as it is neither the snake nor the fish have testes (for they have been seen coupling and with the channels full of semen). It remains then that they are for the better in some way... Those who need to be more temperate have in the one case [of nutriment] intestines that are not straight, and in the other case [of sexual reproduction] their ducts twisted to prevent their desire being too violent and hasty. The testes are built (μεμηχανημένοι) for this; for they make the movement of the spermatic secretion steadier ...

By postulating that the actions of formal natures are either necessary or for the better, Aristotle is able to reconstruct the status of a part as either a necessary prerequisite for the performance of a necessary function (here: ducts are the necessary prerequisites for male sexual reproduction), or as a subsidiary part that helps the performance of that function in a subgroup of animals (here: testes are for slowing down reproduction in males that are too passionate).

This requirement for nature to produce the necessary parts is only overruled in those rare cases where, as we saw above, the presence of the *typical* necessary part in a certain kind of animal would be in vain: in those cases, nature has to come up with an alternative solution to allow the animal to perform its vital and essential functions.

The animal's basic size and dimensions constitute the second category of features specified in the definition of its substantial being. Nature cannot tinker with them (although environmental factors may cause—relatively small—differences of the more and the less: see *HA* VIII 28), even if changing the size or the dimensions would help to solve design problems. For instance, shorter snakes would have been able to walk well with four feet, and smaller (and hence lighter) elephants would not have needed such sturdy feet, thus enabling them to use their feet for grasping food. However, in both cases, Aristotle takes the animal's size as a causally basic feature and as something that is not up to formal natures to change. Similarly, observation shows that one kind of octopus has one row of suckers, whereas another has two, but this differentiation has nothing to do with teleology (*PA* IV 9, 685b12-16):

> Now while the other octopuses have two rows of suckers, one kind of octopus has a single row. This is because of the length and thinness of

> their nature; for it is necessary that the narrow tentacle should have a single row of suckers. It is not, then, because it is best that they have this feature, but because it is necessary owing to the distinctive account of their substantial being (οὐκ οὖν ὡς βέλτιστον ἔχουσιν, ἀλλ" ὡς ἀναγκαῖον διὰ τὸν ἴδιον λόγον τῆς οὐσίας).

Aristotle suggests that, instead, the differentiation is a *necessary consequence* of the differences in size of the two kinds of octopus. Changing the size or the dimensions of an animal will destroy its functionality or turn it into an altogether different kind of being (cf. *Pol* V 3, 1302b33-1303a2; V 9, 1309b18-35; and VII 4, 1326a35-b2), and is therefore not a possible action for formal natures to perform.

The third category of features specified in the definition of the substantial being of animals is their having (red) blood or being bloodless (that is, having an analogue of blood). This is an important specification (and one of the most important differentia of animals: *HA* I 6, 490b7-32), because it does not only entail the necessity of nature producing blood or its analogue in the animal in question, but also the necessity of producing certain other sets of parts.

For instance, since blood forms the matter and nourishment for the whole body (see, e.g., *PA* II 3, 650b6-7; II 6, 652a6-7; and III 5, 668a5-13), every blooded animal must have parts for the production of blood and for its distribution. This means, among others, that the formal natures of blooded animals have to produce a heart (*PA* II 1, 647a35-b8 and III 4, 665b10-15), blood vessels (*PA* III 5), and a liver (*PA* IV 2, 677a36-b5): "For it is reasonable that, since the nature of the liver is vital and necessary to all the blooded animals, its being of a certain character is a cause of living a shorter or longer time. ... and none of the other viscera is necessary to these animals, but only the liver." Together with the heart, which is the origin of blood, the presence of the liver is so basic to the life and survival of blooded animals that no blooded animal can live without it; the presence of the heart and the liver is required in *all* blooded animals (cf. *PA* III 4, 665a28-30, 665b10, 666a24-25 and III 7, 670a23-8). The other visceral parts, such as the kidneys and the spleen, are not in the same way necessary for all blooded animals (see, e.g., *PA* III 7, 670b23-7: "the kidneys are present in those that have them *not of necessity*, but *for the sake of the good and doing well*), and are therefore not present in all blooded animals (cf. *PA* III 9, 671a26-30 and III 12, 673b12-14). The bloodless animals, of course, have no viscera, but only an analogue of the heart (*PA* IV 5, 678a26-b3).

Furthermore, the blooded- or bloodlessness of an animal also puts restrictions on the amount of appendages formal natures can attach to it. Aristotle believes that being blooded correlates universally with (and possibly causes: *see IA* 6, 707a6-21) having a maximum of four points of motion, and hence of having a

maximum of four appendages or locomotive parts (*HA* I 5, 490a26-b1). Formal natures therefore cannot give more than four appendages to blooded animals, even if that would solve problems in their design (see again *IA* 8, 708a9-20, quoted above). For bloodless animals there is no such restriction: they can receive four or more appendages, as long as the total number remains even (*IA* 8, 708a21-b17; cf. *PA* IV 6, 682a35-b4).

A final feature that is likely specified by the definition of an animal's substantial being is the ratio—or, "recipe"—for its material make-up, which determines the proportion of the material elements that are to be used in the production and constitution of the animal in question (cf. *PA* I 1, 642a22: λόγον τῆς μίξεως).[25] Just as there is a specific ratio of the mixture for each of the body parts (*DA* I 4, 408a13-18), there is a specific, generic ratio for each kind of animal (and perhaps even for each gender within that kind: cf. *GA* IV 2, 767a13-28). Birds, for instance, "are all constituted from the same material" (*PA* IV 12, 694b18), and since this is a "given," formal natures will just have to make do with this material in their production of all the subspecies of birds (694b17-20). Similarly, in Aristotle's discussion of the different modes of reproduction in GA II 1, 732a25-733b23, the differences in the elemental make-up of animals, in combination with the amount of internal heat they have, are treated as givens, which then cause the differences in perfection in the modes of reproduction (see especially 732b27-29).

However, even though the *recipe* for an animal's material nature is thus likely determined by its form, the resulting material nature itself can act independently of the form and may pose restrictions on the actions of formal natures. For instance, if an animal lacks the appropriate materials for the construction of certain parts, it will also lack the parts; if it has them, but not in sufficient amounts, it will lack some of the parts, as formal natures "cannot (ἀδυνατεῖ) distribute excess materials to multiple locations at the same time" (*PA* IV 10, 655a28-9).[26] Even if formal natures "want to", it is often impossible to counteract the material natures (see *GA* IV 10, 778a4-9; *PA* IV 5, 682a1-8; and *Pol* I 5, 1254b27-33).

In short, even though Aristotle makes very little direct reference to the "instructions" contained in the definition of the substantial being of the animal, a good deal of its structural and functional features turn out to be predetermined by it. On the other hand, the actions of formal natures are not exhausted by doing what is necessary; they can also do what is possible, better, or best.

3. Decisions up to formal natures: doing what is possible, better, or best

Aristotle's depictions of formal natures acting as craftsmen are richest where the instructions provided by the definitions of substantial beings appear to be

underdetermined. In particular, these instructions turn out to be silent about such questions as *how many* parts a formal nature should produce, *where* in the animal's body they should be placed, and what they should do with extra materials. In reconstructing the causes for why each animal species ends up functioning and looking the way it does, Aristotle often invokes teleological principles, which posit certain rules of actions formal natures "always" or "never" follow when producing the animal in question. I will discuss the two most prominent of these teleological principles and specify the underlying decision-procedures that Aristotle attributes to formal natures in designing animals.

Rule 1: Use extra materials for a purpose, when possible and if this improves the animal

We already encountered (in section 2, above) the first teleological principle, which assumes that, as a general rule, "nature does everything either because it is necessary or because it is better". I suggested that Aristotle uses the principle to identify whether a part is necessary for the performance of a function that is specified by the animal's substantial being, and *must* therefore be produced by the formal nature, or whether it is rather subsidiary and therefore not present in all that perform the function in question. The second part of the principle is of special interest here, because the contrast of subsidiary parts with those that are necessary suggests that the former are *optional* for formal natures: whereas necessary parts are the result of actions natures perform "because it is necessary", subsidiary parts are the result of actions natures perform "because it is better". Aristotle often refers to these latter parts as being "for the better", indicating—as we saw in section 1 above—that these parts are not conditionally necessitated by the animal's form, but are rather due to formal natures making use of extra materials that have come to be of material necessity.

Whether or not formal natures produce such subsidiary parts, depends, first, on whether or not such extra materials are available (and if so, whether they have the appropriate material potentials such that they can be used for improvements of the animal's design), and second, on whether the feature that can be made from those materials is in fact "for the better" for the animal in question. This second condition raises an important question: for how do natures "know" what extra features will improve the well-being or functionality of an animal? For instance, in discussing the use of the "earthen and warm" residues in birds (*PA* IV 12, 694a22-b11), Aristotle says that "in some [nature] constructs length for the legs, in others—instead of this—it fills the gaps in their feet." In both cases, the use natures make of identical materials is for the better given each bird's specific way of life, but how do natures determine this? I address this question below, after first discussing the second rule of action for formal natures, in which the

language of choice and deliberation is even more prominent.

Rule 2: always do what is best, given the possibilities

The second teleological principle assumes that "nature does nothing in vain, but always, given the possibilities, does what is best for the substantial being of each kind of animal".[27] In section 1, we saw that Aristotle invokes the first part of this principle for the explanation of "paradoxical" *absences* of parts. Here I focus on the second part, which Aristotle invokes to explain the *presence* of parts (or their differentiations) in cases where comparative observation with wider or related kinds shows that there are several possibilities in which nature *could* have fulfilled a certain functional need. If we assume, as Aristotle does, that this distribution of features in the animal world is not random, we can discover its causes by thinking about natures as designer-craftsmen.

The thought experiment works as follows: think of the options among which nature can choose as a fixed range, that is, as consisting of the observed range of (the relevantly similar) features realized in actual animals (the hypothetical design space is thus not completely open, but limited to *natural* possibilities).[28] Assuming, then, that natures match each possible part with the animal that is most fitted to use that part, we should investigate the animal's substantial being (which, in principle, is fixed and cannot be tinkered with), and see if we can identify what aspect of it prompted natures to distribute the parts in the way they did. Take Aristotle's explanation of why human beings have hands instead of forelimbs (*PA* IV 10, 687a6-18):

> And being upright in nature, humankind has no use for forelimbs, and instead of these, nature provides arms and hands... It is reasonable that *because of their being most intelligent*, they received hands. For hands are instruments, and nature always distributes—like an intelligent human—each thing to the one who can use it... So if it is better thus, and nature does, among the possibilities, what is best (ἡ δὲ φύσις ἐκ τῶν ἐνδεχομένων ποιεῖ τὸ βέλτιστον), it is not because they have hands that humans are most intelligent, but because they are the most intelligent of animals that they have hands.

All blooded live-bearing and land-dwelling animals have forelimbs, but humans have hands, and this distribution cannot simply be explained by reference to the (generic) function these parts perform: both are for grasping. Instead, Aristotle appeals to the teleological actions of formal natures in "deciding" this distribution: given the two options, hands and forelimbs, hands are the best fit for humans, and the reason why lies in their substantial being. First, since humans walk

upright (this is an essential characteristic: see *PA* IV 6, 686a25-31), they do not need—and therefore do not have—forelimbs for walking. Secondly, and more importantly, since humans are the most intelligent of animals, they are best able to use hands, and it befits natures to give parts to animals that are best able to use them (*PA* IV 10, 687a12-16).

Aristotle believes that formal natures follow the same rule of action when deciding *how many* parts to produce for the performance of functions as well as for deciding *where* to place those parts in the animal body.[29] In each case, empirical observation reveals the range of possibilities (of numbers of parts or of locations in the animal body) from which natures are assumed to choose the best option for each animal, given its substantial being.

In the first case, natures always *assign* or *give* as many parts to animals as are both necessary and sufficient for them to function. If possible, animals have one part for the performance of each function (and never more than one), but if necessary, nature will use the same part for multiple functions.[30] For instance, insects receive many wings and separate parts for drawing in nourishment and for defense, unless they are too small, in which case they only receive two wings (for this number is sufficient for flying) and one piercing tongue (*PA* IV 6, 683a19-25):

> And it is better, where possible, not to have the same instrument for dissimilar uses, but the one that is defensive most sharp, and the one that is to be a tongue spongy and able to draw in nourishment. For where it is possible for two things to be used for two functions without impeding each other, nature is unaccustomed to making things as does the coppersmith who, to economize (πρὸς εὐτέλειαν), makes a spit-and-lampstand; but where this is not possible, nature makes use of the same thing for multiple functions.

Aristotle's point is that while it is certainly possible for natures to "cut down" on the number of parts assigned to many-winged insects, it is not their custom to act frugally. On the other hand, natures also do not assign parts too generously. For instance, animals for which it is possible to receive a means of defensive only receive *one* of these, since that is sufficient (*PA* III 2, 663a17-18);[31] and since defense is a non-necessary function, formal natures only provide such parts to animals that are able to use them—which is mostly to males (*PA* III 1, 661b28-31).

In the second case, natures always *distribute* or *place* parts in a balanced manner in the animal's body: parts receive the most valuable location possible, as long as the balance and symmetry between the two halves of the body (along the up and down, left and right, front and back) is preserved and each part has a counterpart (cf. *PA* II 7, 652a30-3 and *IV* 12, 695a9-13). This rule of balanced distribution explains, for instance, why the heart is located where it is (*PA* III 4, 665b18-21):

"Moreover, its position is at an originative place; for it is near the middle, and more above than below, and more in front than in the rear; for nature places the more valuable item in the more valuable locations (ἐν τοῖς γὰρ τιμωτέροις τὸ τιμώτερον καθίδρυκεν ἡ φύσις), where nothing greater prevents it." The heart is the most important bodily part, which is why it is placed at the most valuable location.[32] Functional needs, however, are always given precedence to the value of a location: hence, four-footed animals receive more hair on their back, which is where the functional need of coverage is highest, whereas humans—whose front and back equally require coverage—receive more hair on the front, which is the most valuable location (*PA* II 14, 658a18-24).

Locations in animal bodies derive their value from their closeness to the origin of the three most important functions of living beings (cf. *IA* 4, 705a31-2: "this distinction is one of function"):[33] the front is where the function of sight originates, up is where the function of nourishment originates, and right is where locomotion originates.[34] These three locations and their counterparts make up the six dimensions of the body, dividing it up in two parts along three axes. This doubleness of the body, then, explains why many parts—such as the sense organs—come in pairs (*PA* II 10, 656b27-657a12):

> As to the position of the sense-organs, all the organs of sense have been ordered by nature in a good way… Each of the sense organs is double on account of the body being double—one part on the right and one part on the left. For because the body is double each of the organs of sense is double, one part the right, the other the left…

Note, by the way, that the doubleness of such parts is no exception to the "economical" workings of nature: Aristotle believes that these parts are one in form, but double in structure, and that this is in fact best, given the doubleness of the body itself.[35]

4. Conclusion: implications for Aristotle's embryology and teleology

My reconstruction above of Aristotle's assumptions about how natures "weigh" the available natural possibilities and choose the best design option for each individual kind of animal shows that many features are not "preprogrammed" by the definition of the substantial beings of animals. The "phenotype" of animals develops gradually, as a result of natures not just doing what is necessary, but also doing what is better and best in response to emerging problems and opportunities. However, this also brings us back to our previous questions: how do natures "know" how to determine what is better or best in those cases, and what do these images of "crafting natures" mean for Aristotle's theory of teleology?

When evaluating Aristotle's craft-imagery of natures, it is important to realize that their ability to produce functional living beings on the basis of forms or "instructions" that are themselves underdetermined does not imply that Aristotle believes that these natures deliberate or entertain conscious intentions. In his defense of natural teleology, Aristotle argues that "it is absurd to think that nothing comes to be for the sake of something unless that which effects the change is observed to deliberate; in fact, *even art does not deliberate*" (*Phys* II 8, 199b26-30). In artificial production, the true efficient cause is art, and thus the psychological states of the artist only matter in the sense that art cannot exercise itself, but operates through the artist. Consequently, there is no need to attribute deliberation to natures, the efficient causes of natural generation.

The imagery does imply, however, that the efficiency of neither art nor nature lies in "blindly" following predetermined models or forms. For instance, the art of shoemaking does not just comprise producing large sets of limited types of identical shoes, but also of making adjustments to a shoe-mold to accommodate the wishes of an especially large-footed or fashion-sensitive client in addition to making good use of the leftover leather materials. Similarly, the "art" of natures, so to speak, comprises a certain level of creativity or problem-solving ability, which is not due to some kind of extra deliberating capacity these natures possess, but rather to their inherent, immanent goal-directedness. At the physiological level, that is, when we translate Aristotle's talk of goal-directed natures into realizations of potentials for form in the manner proposed by Gotthelf (see note 5 above), this means that those potentials have to be equally "creative" or "dynamic". If I am right in assuming that Aristotle's depictions of natures as craftsmen are no mere metaphors, but in fact reflect different causal patterns that underlie animal generation, the potentials for form that guide embryology and the later development of animals cannot be blind, automated self-regulating principles. Rather, they are flexible and complex, and include the capacities to make the best use of extra materials and to respond to emerging problems or possibilities.

In sum, although thinking about formal natures as designer-craftsmen provides a powerful tool for the discovery of the underlying natural causes in animal generation, this does not commit Aristotle to a demiurgic teleology. It does, however, entail that we revise our interpretation of the causal roles played by the potentials for form in the coming to be of animals: their flexible and dynamic nature allows for and in fact demands quite impressive transformations of species, if only at the level of embryogenesis.

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Notes

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[1] On this model of reproduction as 'formal replication', see Gotthelf (1987); Lennox (2001a), 230-232; and Witt (1994b), 222-228. On the sense in which Aristotelian species are eternal, see Cooper (1982) and Lennox (2001a), 131-159.

[2] See *DA* II 4, 415a25-b7; *GA* II 1, 731b24-732a1; *Meta* V 28, 1024a29-31 and VII 8; and GC II 10-11. On the fixity of species in Aristotle, see, e.g., Cooper (1982), 197-222 and Sorabji (1980), 145-6.

[3] These natures, however, operate as internal principles; Aristotle does not endorse the external, providential kind of teleology as presented in Plato's *Timaeus*. On this issue, see Lennox (2001a), 182-204 and (2009), 359-60.

[4] For the idea that Aristotle's understanding of natural kinds is not as such 'anti-evolutionary', see already Balme (1972), 97-98; Granger (1987), 110-116; Henry (2006), 451-455; and Lennox (2001a), 160-162.

[5] My paper thus provides further evidence for Allan Gotthelf's suggestions on how to cash out Aristotle's use of craft-language in non-intentional, physiological terms: see Gotthelf (1987) and Leunissen & Gotthelf (2010), 342.

[6] See Broadie (1990) and Lennox (2001a), 230-232.

[7] Sometimes Aristotle depicts the actions of nature itself as those of a painter: e.g., nature 'sketched in' (ὑπέγραψεν) two blood-vessels running from the heart of the embryo (*GA* II 4, 740a28-9), skeletal analogues in sepia and squids (*PA* II 8, 654a24-6), and hair on human chests (*PA* II 14, 658a21-3), and it 'decorated' (ἐπικεκόσμηκεν) long tails with hair (*PA* II 14, 658a31-5). Cf. Aristotle's comparison of blood-vessels to a frame-work (ὡς περὶ ὑπογραφὴν) in *GA* IV 1, 764b30.

[8] Cf. Broadie (1990), 396-398.

[9] Cf. Gotthelf (1987), 184n.46 on natures 'deciding' how many stomachs and sets of teeth to give a certain animal: 'It would not be amiss to see a vague developmental hypothesis in the background.'

[10] Some of the examples are discussed more fully in Leunissen (2010); here I reexamine them with a focus on Aristotle's views on animal design.

[11] On the scientific status and use of teleological principles, see Lennox (2001a), 182-204 and Leunissen (2010), 112-151.

[12] This does not mean that according to Aristotle everything in nature must be present for a purpose (see *PA* IV 2 677a15-18), but rather that formal natures cannot perform non-purposeful actions, such as placing horns on bulls' shoulders (*PA* III 2, 663a34-b13); cf. also *PA* II 8, 653b27-9 and II 9, 654b23-4.

[13] On cases where the actions of formal natures are compromised or restricted by the animal's material nature, see Lennox (2001a), 182-204 and (2001b), 228; on animals lacking parts due to a 'deformation of their kind', which goes back to a material distortion during embryogenesis (cf. *HA* VIII 2, 589b29-590a11), see Granger (1987), 110-16.

[14] For other examples, see *PA* II 13, 658a6-10; IV 11, 690b14-18; IV 12, 694a16-18; IV 13, 696a10-15; IA 2, 704b12-18; 4, 705b25-29; *Resp.* 10, 476a11-15; and GA V 1, 781b22-8.

[15] Using the format of the *Posterior Analytics*, the explanation would run as follows: premise 1: having (a maximum of) four feet holds of no blooded animal whose length is out of proportion to the rest of its body; premise 2: having the length out of proportion to the rest of their body holds of all snakes (which are blooded animals); conclusion: having (a maximum of) four feet holds of no snakes.

[16] The Greek is (παρα)καταχρῆται; see *PA* II 16, 659b34-660a2; III 9, 671a35-b2; *IV* 10, 688a19-25, 689a5-7, 689b34-690a4; and *Resp.* 7, 473a23-5.

[17] See Gotthelf (1997a).

[18] There is a slightly different (and unique) case where Aristotle suggests that

nature *remedies* a problem with the positioning of one part by constructing another: because of other necessitating factors, nature has to place the windpipe in front of the esophagus, where 'it is interfered with by the food' (*PA* III 3, 664b20-1). So, in order to prevent food from slipping down the windpipe, nature 'has constructed the epiglottis' (664b21-22), to 'remedy (ἰάτρευκεν) the badness of the position of the windpipe' (665a7-8).

[19] I call this causal process of natures *making use* of materials that have come to be of material necessity 'secondary teleology', using 'primary teleology' for the realization of a potential for form through stages shaped by conditional necessity (conform Gotthelf's 1987 interpretation of teleology): see Leunissen (2010).

[20] Code (1997), 139-140 and Gotthelf (1985), 27-54; (1987), 190-191.

[21] *PA* II 8, 653b19-23 (cf. II 2, 647a20-3); IV 12, 693b2-13; and IV 13, 695b17-25.

[22] *PA* III 6, 669b8-12 and IV 8, 684a32-b1.

[23] *PA* IV 9, 685b12-15 (cf. IA 8, 708a9-20); *PA* IV 6, 683a18-19; *IA* 8, 708a9-20; *GA* II 6, 745a5-6; *DA* II 4, 416a15-18; and *Pol* V 9, 1309b18-35.

[24] *PA* IV 5, 678a31-5; IV 12, 693b2-13; and IV 13, 695b17-26.

[25] Cf. Gotthelf (1987), 192-193.

[26] See also *PA* III 2, 664a1-3 and IV 12, 694a28. Lennox (2001a, 192-3) suggests that natures follow a 'principle of functional priority' in deciding how to use the available materials in these cases.

[27] See *IA* 2, 704b12-18; 8, 708a9-12; and 12, 711a18-29.

[28] Lennox (2001), 214-215.

[29] Cf. Lennox (2001a), 189 and 203n.16. Natures even follow this rule for deciding when to produce parts: see *GA* II 6, 744a35-b1 and *GA* V 8, 788b20-789a2.

[30] See *PA* II 16, 659a20-2; III 1, 661b28-31 and 662a18-24; IV 7, 683b5-7; IV 8, 684a27-30; IV 10, 687a10-15 and 689a4-15; cf. *GA* I 1, 716a24-7.

[31] Cf. Aristotle's remark about the heart that 'wherever possible, one origin is better than many' (*PA* III 4, 665b14-15; cf. 665b28-31).

[32] See also *PA* III 3, 665a23-6; III 7, 669b18-26 and 670a4-7; III 10, 672b19-24; IV 11, 691a28-b4; *GA* I 8, 718b25-9; I 11, 719a13-15; II 1, 732a3-8; *IA* 2, 704b18-22; *Cael* II 2, 284b10 and 285a11; and III 4, 303b2.

[33] See Balme (1987), 277 and Lennox (2001a), 266-272.

[34] See *PA* II 10, 656b22-5; III 3, 665a13-15; IV 7, 683b19-24; *IA* 4, 705a29-b5 and 706a21-5; and 5, 706b12-16.

[35] Cf. *PA* III 7, 669b36-670a7. On the doubleness of the body, see Lennox (2001a), 267-72 and (2001b), 227.

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