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Devin Henry, *The University of Western Ontario*



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OPTIMALITY REASONING IN ARISTOTLE'S NATURAL TELEOLOGY

DEVIN HENRY

IN this paper I examine the use of optimality reasoning in Aristotle's natural teleology, with special attention to its application in the domain of living things. By *optimality reasoning* I mean reasoning that appeals to some idea of optimal 'design' in order to understand why things are the way they are. In Aristotle, such optimality reasoning is expressed by his famous principle that nature does nothing in vain but always what is best for the substance given the range of possibilities (*IA* 2, 704^b12–18, translated below). My aim in this paper is to shed light on Aristotle's use of this principle in his account of natural substances.¹ How do we understand the concept of 'the best' at work in the principle? How does Aristotle conceive

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¹ In spite of the importance of this principle in Aristotle's natural science, there has been surprisingly little scholarship devoted to it. The seminal work on the subject is J. G. Lennox, 'Nature Does Nothing in Vain', in H.-C. Günther and A. Rengakos (eds.), *Beiträge zur antiken Philosophie: Festschrift für Wolfgang Kullmann* (Stuttgart, 1997), 199–214; repr. in J. G. Lennox, *Aristotle's Philosophy of Biology* [*Philosophy of Biology*] (Cambridge, 2001), 205–23 (all references herein are to the reprint). To my knowledge, the only other major work on this principle is P. Huby, 'What Did Aristotle Mean by "Nature does Nothing in Vain"?' ['Nothing in Vain'], in I. Mahalingam and B. Carr (eds.), *Logical Foundations* (Hong Kong, 1991), 158–66, and M. Leunissen, *Explanation and Teleology in Aristotle's Science of Nature* [*Explanation and Teleology*] (Cambridge, 2010), s.vv. 'nature: does nothing in vain' and 'nature: does what is best, given the possibilities'. See also M. R. Johnson, *Aristotle on Teleology* [*Teleology*] (Oxford, 2005), s.v. 'nature: nothing in vain', and A. Gott-

of the range of possibilities here? And what role does optimality reasoning play in Aristotle's natural science? I begin by looking at the roots of optimality reasoning in Plato, which provides the intellectual backdrop for Aristotle's principle. As we shall see, while both Plato and Aristotle view the natural world (or at least part of it) as the product of an optimizing agent and while both see this assumption as licensing a pattern of reasoning that appeals to a certain conception of 'the best', they disagree fundamentally over what the optimization agent is and how it operates.

1. Platonic origins

We are first introduced to optimality reasoning in the famous passage at *Phaedo* 97 B 8–98 A 2, where (Plato's) Socrates invokes 'what is best' as a cause (*αἰτία*) of things in nature. As Plato tells the story, Socrates took Anaxagoras' idea that Reason 'directs and is the cause of everything' and grafted onto it the notion of optimization. Socrates explains: '*I thought* that if this were so, then Reason should direct everything and arrange each thing in the way that was best.' This is supposed to ground the explanatory strategy introduced next: 'If, then, one wished to know the cause of each thing, why it comes to be or perishes or exists, one had to find what was the best way for it to be, or to be acted upon, or to act.' Notice the pattern of inference here. *If* the world is arranged by an optimizing agent (assumption), *then it follows* that we can explain why things are the way they are by demonstrating that they are in the best possible state. Socrates goes on to provide an example of what an explanation of the sort he is after might look like:

As I reflected on this subject I was glad to think that I had found in Anaxagoras a teacher about the cause of things after my own heart, and that he would tell me, first, whether the earth is flat or round, and then would explain why it is so of necessity,² saying which is better, and that it was better to be so. If he said it was in the middle of the universe, he would

help, *Teleology, First Principles, and Scientific Method in Aristotle's Biology* [*First Principles*] (Oxford, 2012), s.v. 'natures: as doing nothing without a point'.

² According to *Timaeus*, the primary agent responsible for order in the cosmos is the Demiurge, who is supremely good. And *Timaeus* claims that it is *not possible* for one who is supremely good to do anything except what is best (29 E 1–2). Therefore, everything the Demiurge creates *must of necessity* be in its optimal state (29 D 7–30 A 7).

go on to show that it was better for it to be in the middle. And if he showed me those things, I should be prepared never to desire any other kind of cause. (97 D 5–98 A 2, trans. Grube)

The example suggests two stages to the account: (1) a description of the empirical facts concerning the shape of the earth; and (2) a statement of the *aitia*, which tells us that the earth is the way it is *because* that is the best way for it to be. A close analysis of the *Phaedo* passage thus suggests that what Socrates is offering here is a two-part model of explanation. The first part calls for a descriptive account of the explanandum, while the second part involves identifying the optimum, which tells us the best way for that phenomenon to be. We will have *explained* the phenomenon (given its *aitia*) when we have shown that the facts described in the first step match the optimum revealed in the second. In this way, the fact that round *is* the best shape for the earth to be explains why it has the shape it does.

Famously, Socrates' initial enthusiasm for optimality reasoning in the *Phaedo* gave way to thoughts of another pattern of explanation, namely, one that invokes Forms as explananda. Yet Socrates never rejects the teleological model. Instead the *Phaedo* leaves us with two forms of adequate explanation, one that makes use of optimality reasoning and one that appeals to Forms. There are no suggestions in that dialogue as to how these two are supposed to fit together into a unified pattern of explanation or, indeed, if they do. Instead, developing a more integrated theory of scientific explanation is left for the *Timaeus*. According to Sedley, Plato's use of teleology in the *Timaeus* moves us even further away from the empiricism of Presocratic natural science towards a conception of natural science as 'an exercise of pure thought'.³ Here optimality reasoning becomes an *a priori* attempt to reconstruct, independently of experience, the pattern of reasoning that went into the world's design by the creative *Nous*. On Sedley's reading, it is irrelevant to Plato's project in the *Timaeus* whether or not our observations about the actual world tally with our reconstruction of the Demiurge's reasoning process. The guiding question is simply: what would *reason itself* judge to be best? For Sedley, this armchair approach to causal enquiry forms part of Plato's ongoing attempt to 'intellectualize' natural science (110).⁴ Although my focus in this paper is on Aristotle's use of op-

³ D. Sedley, *Creationism and its Critics in Antiquity* [*Creationism*] (Berkeley, 2007), 109–12.

⁴ For other interpretations of the *Timaeus*' account of teleology see: S. K. Strange,

timality reasoning, I should say a few words about how much of my account depends on this particular way of understanding the *Timaeus*.

As mentioned, part of the argument of this paper is that both Plato and Aristotle took the natural world to be the product of an optimizing agent and that both saw this claim as licensing the use of optimality reasoning in natural science but that they disagreed fundamentally over what the optimization agent is and how it operates (see Section 6 below). My analysis of these fundamental differences will depend mainly on the claim that Plato thought the world was intelligently designed by a divine craftsman. This is a consistent theme running through several of Plato's dialogues (e.g. *Republic*, *Philebus*, *Laws* 10). And while not everyone agrees on which details of Plato's creationist account he intended to be taken seriously,⁵ most commentators (ancient and modern) at least take the basic claim of intelligent design as axiomatic.⁶ Now the teleological explanations in the *Timaeus* that appeal to optimization are *prima facie* accounts of the reasoning process that went into the design of some feature of the cosmos. If Plato accepted that the world was put together by a Divine Craftsman who deliberated about what was best for each thing, then it is reasonable to suppose that those accounts

'The Double Explanation in the *Timaeus*', in G. Fine (ed.), *Plato 1: Metaphysics and Epistemology* (Oxford, 1999), 397–415; Lennox, *Philosophy of Biology*, 280–302; T. K. Johansen, *Plato's Natural Philosophy: A Study of the 'Timaeus–Critias' [Natural Philosophy]* (Cambridge, 2004); and S. Broadie, *Nature and Divinity in Plato's Timaeus [Nature and Divinity]* (Cambridge, 2012).

⁵ The main disagreements surrounding the *Timaeus*' creation story are the separateness of the Demiurge (Johansen, *Natural Philosophy*, ch. 4; Broadie, *Nature and Divinity*, ch. 1) and what Broadie calls the 'proto-historical inauguration' of the cosmos (*Nature and Divinity*, 243).

⁶ As is well known, the *Timaeus* itself is full of remarks describing the account as *εἰκώς*. Some take this to mean that the entire creationist story is only metaphorical. See e.g. F. M. Cornford, *Plato's Cosmology* (London, 1937), 31–2. But *εἰκώς* need not be read in that way. Indeed, as Johansen notes (*Natural Philosophy*, 50), there are several passages in the *Timaeus* where the claims being made are described as 'true'. On my reading, 'Timaeus' remarks are meant to suggest that we should not expect an enquiry into the world of becoming to yield stable, precise knowledge; our grasp on the subject-matter reaches no higher than belief (*πίστις*) (*Tim.* 27 D 5–29 D 3; cf. *Rep.* 6, 509 A 6–513 E 3). (See *Phileb.* 58 B 9–59 D 8. Compare Aristotle's remarks in the *Nicomachean Ethics* about the level of precision we should expect from an enquiry whose subject-matter is imprecise and holds only for the most part.) On this reading *εἰκώς* modifies how closely our accounts approximate certain truth (they are only 'likely'), not whether those accounts should be taken literally or metaphorically (Johansen, *Natural Philosophy*, 51–2).

are meant to capture the chain of inferences that the Demiurge himself followed in working out his designs. This does not mean that Plato thinks human optimality reasoning is *an exact* reconstruction of the Demiurge's thought-process; such reasoning is at best *a likely* reconstruction.⁷ Finally, while I think Sedley is right that Plato thought that optimality reasoning in the *Timaetus* could be carried out entirely independently of experience, nothing substantial in this paper hinges on that claim. Indeed, as we shall see, there is at least one reason for thinking that this might not be the case (though not a decisive one).⁸

2. Nature does nothing in vain

The optimality reasoning outlined in *Phaedo* 97 B 8–98 A 2 and employed throughout the *Timaetus* can be seen as the intellectual ancestor of Aristotle's own famous principle, whose full expression is found in the following passage:

We must begin the investigation by laying down as suppositions those things we often use in natural enquiry, grasping that this is the way things are in all the works of nature. One of these is that nature does nothing in vain but always what is best for the substance from among the possibilities concerning each kind of animal; for this reason, if it is better this way, then it is that way and being in that state is in accordance with nature. (*IA* 2, 704^b 12–18)

Two preliminary remarks about Aristotle's optimality principle are in order here.

⁷ See Sedley, *Creationism*, 111; cf. previous note.

⁸ That reason has to do with the role of constraints in the *Timaetus*, to which I shall return. If Sedley is right about this last claim, then it would mean that the *Timaetus* is an even more extreme form of rationalism than the *Phaedo*. Sedley argues that optimality reasoning in the *Timaetus* proceeds without regard to empirical data: 'If by good fortune the unfolding story of how the world was devised and built in fact proves to tally with the data of our experience, that is something the reader is no doubt expected to note in its favor, but is no part of the actual argument for it' (*Creationism*, 109). At least judging from Socrates' example of what a proper teleological explanation would look like at *Phaedo* 97 D 5–98 A 2, interpreting the empirical data through our understanding of optimal designs is central to the teleological enterprise of the *Phaedo*. In the *Phaedo* the value of optimality reasoning is that it helps make our empirical observations about the world intelligible ('Why *is* the earth round? Because that is the optimal shape for the earth'). Of course this reading is consistent with Sedley's interpretation, since it only suggests that the teleological approach espoused by Timaeus is further on its way towards 'intellectualizing' physics than anything Socrates had hoped to get from Anaxagoras in the *Phaedo*.

First, I take the proposition that nature does nothing in vain but always what is best for the substance from a range of possibilities to express a single unified principle. By contrast, Lennox argues that there are two separate principles here: ‘nature does nothing in vain’ (his NP), which is used to explain the *absence* of features; and ‘nature always does what is best’, which is used for those features that are *present* because they are better for the animals that possess them. Although doing nothing in vain and doing what is best certainly express different ideas, I am not convinced that Aristotle sees these as separate principles to be invoked in different explanatory contexts. Aristotle certainly does not treat them as separate principles in the above passage. Nor does he always do so in practice. For example, at *IA* 8, 708^a9–20 (discussed below), Aristotle invokes the whole principle as part of the explanation for the *absence* of legs in snakes. And *GA* 2. 5, 741^b4–5, appeals to the fact that nature does nothing in vain to account for the *presence* of males in animals.⁹ While I will often shorten the optimality principle for convenience, we should assume that the entire principle is at work.

We also need to say something about the ‘nature’ whose actions are governed by this principle. Aristotle often characterizes the productive activity of nature using the language of design. Nature is said to devise (*mēchanatai*) clever mechanisms (*PA* 652^a31). It is described as a kind of superintendent that seeks (*bouletai*) to regulate the gestation periods of animals according to the cycles of the heavens (*GA* 778^a4). And it is compared to various craftsmen, including a painter (*GA* 743^b20–5), a sculptor (*GA* 730^b24–33), a carpenter (*GA* 730^b19–23; 740^b25–741^a3), and a housekeeper (*GA* 744^b16–27). In at least two places Aristotle even uses the phrase ‘demiurgic nature’ (*hē dēmiourgēsasa phusis*: *PA* 645^a9–11; *GA* 731^a24), which is reminiscent of the language of the *Timaeus*. Such strong design language might be taken to suggest that what Aristotle is talking about here is some kind of Cosmic Nature on a par with Plato’s Demiurge.¹⁰ Yet, however tempting this inference may be, Aristotle’s personification of nature can only be metaphorical. For there is little evidence that he thinks of nature as an intelligent designer.¹¹ Indeed, Aristotle’s theoretical account

⁹ Leunissen, *Explanation and Teleology*, 130.

¹⁰ Huby, ‘Nothing in Vain’.

¹¹ Lennox, *Philosophy of Biology*, 184; Johnson, *Teleology*, 80–1; L. Judson, ‘Aristotelian Teleology’, *Oxford Studies in Ancient Philosophy*, 29 (2005), 341–66 at 361; and Leunissen, *Explanation and Teleology*, 17–18, 61–2, 126.

of nature positively tells against that reading. In *Physics* 2. 1 nature is defined as 'a principle or cause of being changed and being at rest *in* that to which it belongs primarily, in virtue of itself, and non-incidentally' (192^b20–3). Nor do any of the senses of *phusis* canvassed in *Metaphysics* 5. 4 refer to the concept of a Cosmic Nature. In *Physics* 2. 6 Aristotle explicitly contrasts nature with intelligence (and craft) as distinct kinds of moving cause (e.g. *Phys.* 198^a2–4; cf. 192^b8–34 and *GA* 735^a2–4). Finally, in *Physics* 2. 8 he rejects the idea that natures are rational agents that deliberate about their ends (199^a20–6; 199^b26–8).¹²

Having said that, in what follows I shall continue to employ the language of engineering and design despite its potential to mislead because it is a very convenient way of talking about optimality. Indeed, as we have just seen, Aristotle himself uses that language. But, again, such language is not meant to imply that Aristotle thinks of nature as a rational agent engaged in deliberation. Instead, the optimality principle should be understood as a generalization over the goal-directed actions of the formal natures of particular natural substances (for example, the formal natures *of snakes* do nothing in vain).¹³

We can illustrate Aristotle's use of optimality reasoning by looking at two examples from the text. The first is his explanation for the peculiar jaw configuration of the river crocodile at *PA* 4. 11, 691^a27–^b15. Aristotle begins by noting that birds, fish, and four-footed egg-layers all have jaws that move up and down rather than from side to side (as they do in humans). The reason, he tells us, is that side-to-side motion is useful only for animals with grind-

¹² *Physics* 2. 8 has become the dominant focus of scholarship on Aristotle's natural teleology for the past several decades. The primary battleground for the different sides of the debate has been the so-called rainfall argument at 198^b17–199^a8. For a survey of the major positions within this debate see R. W. Sharples, 'The Purpose of the Natural World: Aristotle's Followers and Interpreters', in J. Rocca, *Teleology in the Ancient World* (Cambridge, 2013, forthcoming). I will not enter the fray here. Instead I shall limit myself to the role of optimality reasoning in the case of living things whose adaptations are incontrovertibly teleological in Aristotle's view. Most scholars agree that Aristotle's teleology does not depend on conscious intentionality in this context.

¹³ See also Lennox, *Philosophy of Biology*, 184; Leunissen, *Explanation and Teleology*, 119 (though see 123); and Gotthelf, *First Principles*, 171. For the claim that 'the formal nature' of a natural substance is the primary moving cause of its generation see *Metaph.* Z 7, 1032^a20–5 (cf. *GA* 4. 4, 770^b15–17). At *GA* 2. 4, 740^b25–34, Aristotle identifies the productive nature that constructs the parts of a living thing with the active power (*ποιούσα δύναμις*) of its nutritive soul.

ing teeth. And since these animals lack grinding teeth, having jaws that can move sideways would have been in vain. Since nature does nothing in vain, it follows that these animals will possess jaws that move up and down only. Aristotle then notes that the river crocodile is peculiar in that it is the only four-footed egg-layer whose mouth is set up so that its upper jaw moves while the lower jaw remains stationary (which is the reverse of the normal configuration). Again Aristotle explains this feature using principles of optimization. Crocodiles have very small front limbs that are ill-equipped for grasping food. As a result, nature has ‘designed’ their mouths not only for chewing but also for seizing and holding their prey. There are at least two possible ways to configure the jaws to do this: have the bottom jaw move up and down, or have the upper jaw move up and down. Of these two possibilities, the latter configuration turns out to be the most useful for the crocodile:

Relative to seizing prey and holding onto them, the more useful movement for striking a blow is the one that has the greatest force. And a blow from above is always more forceful than one from below. And to an animal that has no hands or proper feet and which has to use its mouth for seizing food as well as for chewing it, the power to seize it is more necessary. Therefore it is more useful for the crocodile to be able to move its upper jaw than its lower one. (*PA* 4. 11, 691^b9–15)

While the crocodile could have been built with a mouth whose lower jaw moved up and down (standard issue for a four-footed egg-layer), having its upper jaw move turns out to be the best jaw design for a crocodile from among the range of possibilities.

A second example of Aristotle’s use of optimality reasoning is afforded by his explanation for why snakes have no legs:

The cause [*aitia*] of why snakes are footless is both that nature does nothing in vain but in every case acts with a view to what is best for each thing from among the possibilities while maintaining the distinctive being and essence of the thing itself, and, as we have said, because no blooded animal can move by means of more than four points. It is clear from this that of all blooded animals whose length is out of proportion with the rest of their bodily constitution, such as snakes, none of them can be footed; for they cannot have more than four feet. If they had, they would be bloodless. Whereas, if they had two or four feet, they would be practically incapable of any movement at all, so slow and useless would their movement be of necessity. (*IA* 8, 708^a9–20; cf. *PA* 4. 13, 695^b17–26)

The absence of legs in snakes is something that demands explanation because they are the only blooded land-dwellers that lack this feature. Given their unusual length, we might have expected nature to have equipped snakes with a lot of legs like a centipede. However, Aristotle has already established in *IA* 7 (discussed below) that no blooded animal can move at more than four points of motion. So the most legs a snake could have would be four. But giving four legs to a snake would obviously be pointless, since snakes could not move effectively with only four (cf. *PA* 4. 13, 696^a12–15). Therefore, legs on a snake would be in vain. And since nature does nothing in vain but always what is best for an animal given the range of possibilities, it follows that snakes do not have legs.

Why not just shorten the snake's body in order to accommodate four legs? As the above passage makes clear, the essence of a thing sets prior constraints on what its formal nature can do. This is what Aristotle means when he says that nature does what is best 'while maintaining the distinctive being and essence of each thing itself'. Aristotle seems to treat the elongated body of a snake as one of its essential properties (something it cannot change while still remaining what it is),¹⁴ and so this structural aspect of the snake's design constitutes a built-in feature that must be preserved when trying to optimize its form. If having an elongated body is part of what makes something a snake, then clearly nature could not make *a snake* with a proportionately shorter body.

These examples can help to shed light on what Aristotle means by saying that nature does nothing 'in vain' (*matēn*). For it is not immediately obvious from his use of the optimality principle.¹⁵ One place to look for an answer is *Physics* 2. 6. There Aristotle tells us that the judgement that something *F* is 'in vain' is always relative to its end *G* (197^b23–9).¹⁶ For example, suppose I go to the market (*F*) for the sake of buying fish (*G*), but when I get there I fail to accomplish that goal. In that case we would say that I went to the market 'in vain'. However, Aristotle's use of *matēn* in the optimal-

¹⁴ I discuss the role of constraints below. While this suggestion may strike readers of the *Metaphysics* as questionable, in the biological works Aristotle often includes the parts of animals as well as their physical features in the *oûsía* of a thing (e.g. *PA* 3. 6, 669^b12: lungs; 4. 5, 678^a33–4, and 4. 13, 695^b17–25: being blooded; 4. 6, 682^a35–^b32: being divided into sections; 4. 9, 685^b12–16: length and slimness). See Gotthelf, *First Principles*, ch. 10, and Lennox, *Parts of Animals*, 314.

¹⁵ I am grateful to Rachel Barney for pressing me on this point.

¹⁶ Johnson, *Teleology*, 81–2.

ity principle does not obviously conform to this analysis. Here we are supposed to reason counterfactually that, if some feature were present, it would exist in vain precisely because it would lack an end. If crocodiles had jaws that moved sideways, that setup would exist in vain because without grinding teeth it would not serve any function. Likewise, if snakes had legs, their legs would exist in vain precisely because they would not serve any particular end. And yet, according to the *Physics* account, only those things that have determinate ends can be said to exist in vain.

I suspect Aristotle's use of *matēn* in the optimality principle is less technical than the *Physics* 2. 6 account would suggest. Aristotle may just mean that nature never does anything 'for no reason',¹⁷ in which case saying that nature does nothing in vain is equivalent to saying that nature does nothing superfluous (*periergon*, e.g. *GA* 744^a36). However, there is a way to understand the optimality principle so that it conforms to the *Physics* account. The *Physics* tells us that the expression 'in vain' is used whenever something *F* fails to bring about that end *G* for the sake of which it *naturally* (*pephuken*) exists. One way that we might determine a part's natural function is by looking to the widest kind to which that part belongs and asking how most members of the wider kind use that part. For example, a survey of all animals that possess legs (the wider kind) reveals that such animals typically use their legs for locomotion. This provides good inductive evidence that nature's goal in equipping animals with legs is to allow them to move from place to place (cf. *PA* 695^b22–3). Thus we can say that nature would have done something in vain by endowing snakes with legs, since they would not perform the function for which they naturally exist.¹⁸

Having looked at Aristotle's optimality principle in context, let me now turn to my three main questions:

- (1) How are we to understand the concept of 'the best' at work in the principle?
- (2) How does Aristotle conceive of the range of possibilities?

¹⁷ The second meaning of *matēn* listed in LSJ is 'at random, without reason'. See also Johnson, *Teleology*, 80.

¹⁸ We can put the point in less metaphorical terms by speaking of the development of the legs as occurring in vain. In most animals that have legs the developmental process that results in those parts naturally occurs for the sake of locomotion. If this same developmental process were to occur in snakes, it would be 'in vain' in so far as it would fail to achieve its natural end.

- (3) What role does optimality reasoning play in Aristotle's natural science?

I shall take these up in turn.

3. Nature always does 'what is best'

Aristotle seems to take it as axiomatic that being is better than non-being. And since 'to be' for a living thing is 'to be alive', it follows that living is better than non-living (*GA* 2. 1, 731^b28–30; cf. *DA* 2. 4, 415^b12–14). Allan Gotthelf has argued that Aristotle is not appealing to any independent standard of goodness here; rather, the life (or being) of a thing *constitutes* its good. On this account, the parts of a living thing are judged to be good or bad in relation to the contribution they make to the organism's survival and well-being.¹⁹ In the light of this, when Aristotle says that nature always does 'what is best' for the substance, we can take him to mean that the parts of living things have been optimized for contributing to the life of the individual. But does this mean that each part of a living thing exhibits *perfect* design or does Aristotle have in mind something more modest than that?

We can begin to gain some insight into this question by using the discussion of constitutions in *Politics* 4. 1 as a framework. Aristotle tells us that the study of constitutions is the subject of a single science and that part of the job of that science is to determine what sort of constitution is best. However, the student of politics must be careful to distinguish between the *ideal* constitution and the *best possible* constitution given a set of real-world circumstances:

Hence it is clear that constitutions are the subject of a single science, which has to consider what the best constitution is and what its character must be in order to meet our aspirations (when nothing external prevents it from being implemented), and what sort of constitution is suited to which particular city. For the best constitution is often not attainable, so that the good legislator and true statesman must consider what is the most excellent in the unqualified sense [τὴν κρατίστην ἀπλῶς] and what is best given the underlying conditions [τὴν ἐκ τῶν ὑποκειμένων ἀρίστην]. (*Pol.* 4. 1, 1288^b21–6)

¹⁹ A. Gotthelf, 'The Place of the Good in Aristotle's Teleology', in J. J. Cleary and D. C. Shartin (eds.), *Proceedings of the Boston Area Colloquium in Ancient Philosophy*, 4 (1988), 113–39.

Aristotle recognizes that certain constitutions may be the best way of organizing the offices in a *polis* in the abstract but that those sorts of constitution may not be possible given the real-world circumstances. Since the *ideal* constitution may not be the same as the best *realizable* constitution, political science must not only consider theoretical alternatives but empirical ones as well. This same distinction can be applied to the forms of living things. When Aristotle says nature always does what is best for the substance, he does not mean what is best in the unqualified sense, but only what is best given what the circumstances allow. In the case of living things, nature's ability to do what is best is affected by the presence of various biological constraints.

Both Plato and Aristotle appeal to the notion of constraints to explain the fact that the world is not absolutely perfect. At *Tim.* 30 A 3, for example, Timaeus says that the Demiurge desired to produce what is best for the cosmos 'as far as it is possible' (*kata to dunaton*). The nature of the constraints operating on the Demiurge in the *Timaeus*, however, remains controversial. According to Sedley, for example, the Demiurge's creative activities are limited only by competing functional demands; there is no suggestion that matter itself might impose its own independent constraints on what the Demiurge can do.²⁰ Indeed, Sedley argues that it is inconceivable that Plato's theology would tolerate the notion of design faults resulting from the recalcitrant nature of matter: 'Would Plato's theology really allow that the best thing in the universe, god, might on occasion be defeated by the lowliest thing, matter? This is such an un-Platonic thought that very clear evidence would be needed before the point could be safely conceded. I believe there is none.'²¹ On Sedley's reading, the only suboptimality that exists in Plato's world is 'caused by the demands of [functional] biology, not the nature of matter'. By contrast, Johansen argues that the necessary properties and motions of the simple bodies can impose prior constraints on what is possible for the Demiurge to bring about.²² These are cases where the Demiurge is unable to 'persuade' necessity to do as it bids but must instead work within the constraints set by it. For example, at *Tim.* 75 A 7–D 4 we are told that 'there is no way [*oudamēi*] that anything whose generation and composition are a consequence of necessity can accommodate the combination of thick bone and

²⁰ Sedley, *Creationism*, 116–21.

²¹ Ibid. 116.

²² Johansen, *Natural Philosophy*, 101–2.

massive flesh with keen and responsive perception'. The force of this statement seems to be that such a combination is not even possible for the Demiurge himself to bring about. The necessary character of the materials involved will not allow it. Indeed, Timaeus goes on to say that were it not for these material constraints, our heads would have been fortified with thick bones, which in turn would have prolonged our life. This is pretty clear evidence that the Demiurge's ability to produce what is best for the cosmos is not only constrained by competing functional demands but also by the necessary properties of the simple bodies themselves.²³

Aristotle also accepts that the natures of living things operate within the limits of constraints. As a result of these constraints, the best (empirically) *possible* forms often turn out to be worse than the best *conceivable* ones. It is worth dwelling on this at some length because it helps to make clear that his own conception of optimality is not that of extreme perfection.

Aristotle recognizes a number of different biological constraints affecting the empirical possibilities. One type of constraint arises from general considerations of survivability. For example, everything that grows must have parts for taking in and processing food, along with a supply of natural heat for transforming that food into the raw materials used to nourish its body (*PA* 2. 3, 650^a2 ff.). This means that nature cannot design a *viable* organism without parts that satisfy these demands: hence animals have parts like hearts and livers. We have also seen how the essence of a thing sets prior constraints on the actions of its formal nature. As Aristotle puts it, nature always does what is best 'while maintaining the distinctive being and essence of each thing itself' (*IA* 8, 708^a11–12). In these cases the constraint in question is rooted in the definition of the animal's substantial being. If part of what it is to be a snake is to be a blooded animal whose length is out of proportion with the rest of its body, then nature cannot make a snake with a shorter body. For such an animal would not *be* a snake by definition.²⁴ The existence of competing functional demands is a third source of biological constraint. For example, Aristotle treats the elephant's trunk (*PA* 2. 16) and the fact that fish are so prolific (*GA* 3. 4, 755^a11–^b1) as trade-

²³ Sedley, *Creationism*, 121–2, acknowledges this example but denies that it has anything to do with constraints imposed by matter. I do not find his explanation of this passage convincing.

²⁴ See also *PA* 2. 16, 659^b6–13, and 4. 13, 695^b17–26.

offs between multiple and conflicting functions: in the case of the elephant the functions of breathing and locomotion, in the case of the fish different functions associated with reproduction.

The above three cases can be classified as constraints arising from the formal and final cause. But Aristotle also allows that certain features of a thing's material nature can set prior constraints on what its formal nature can do. (These are cases where the matter is not itself conditionally necessitated by form.) There are at least three ways that features of the material nature can act as a constraint on form.²⁵

In some cases the amount of material available during development imposes prior constraints on what the formal nature is able to achieve. Here nature is analogous to an engineer whose hands are tied by the fact that his supplier did not provide him with enough raw materials to do his job. For example, Aristotle notes that all horn-bearing animals lack incisors in both jaws (an empirical observation). The cause of this, he tells us, is the fact that ruminants lack sufficient developmental resources to produce *both* horns *and* a complete set of teeth. This lack of raw materials thus imposes constraints on the production of those parts (*PA* 3. 2, 663^b28–664^a2). In order to compensate for the decrease in mastication created by the absences of incisors, nature has equipped ruminants with a multiple-chambered stomach (*PA* 3. 14). Notice that this is not the result of a trade-off between competing functional demands, since the functions of horns and teeth do not conflict. Instead the lack of incisors results from the fact that the supply of available matter during development sets limits on what the formal nature can build.

In addition to developmental constraints, the basic material constitution of an animal can also prevent nature from achieving perfection. In *De generatione animalium* Aristotle treats the ability to generate live young as the most perfect form of reproduction (*GA* 2. 1, 732^a25–733^b16; 2. 4, 737^b15–27). In a perfect world, then, all animals would be live-bearers. However, Aristotle notes that birds are by nature cold and dry (a property of their material nature) and so lack the necessary vital heat to bring their offspring to completion

²⁵ My account depends on the controversial idea that Aristotle treats certain features of the material nature as causally basic in the sense of being causes of many other features of a living thing while nothing 'more fundamental' (*ἀνωθεν*) is the cause of them (cf. *GA* 5. 7, 788^a14–16). For a defence of this claim see D. Charles, *Aristotle on Meaning and Essence* (Oxford, 2000), e.g. 334–5; Leunissen, *Explanation and Teleology*, e.g. 24–5; and Gotthelf, *First Principles*, ch. 8.

internally. As a consequence of this birds generate externally by laying eggs. In order to compensate for the vulnerability of the embryo nature has endowed birds with the ability to produce a hard-shelled egg, which protects it as it develops. In this way laying hard-shelled eggs represents the best possible way of reproducing *given* the prior constraints imposed on the bird's design by its distinctive material nature. There is no indication anywhere in the text to suggest that Aristotle thinks the particular bodily constitution of birds is itself the result of some teleological demand. Instead he treats this feature of its material nature as causally basic.²⁶

A third kind of constraint associated with a thing's material nature are what we might call *architectural constraints*.²⁷ Here the features of the animal's basic body plan (including its dimensions and the placement of its organs) make some trait physically impossible. This is nicely illustrated by Aristotle's discussion of the oesophagus in *PA* 3. 3. In all blooded animals furnished with lungs the oesophagus is situated behind the windpipe, which makes the animal susceptible to choking. Aristotle does not try to explain this away by showing how choking contributes to some higher function so that this is, in fact, the best conceivable design for a lung possessor. He acknowledges that this is a bad set-up (*phaulotēta*, 665^a8) and that a much better configuration would have been to connect the stomach directly to the mouth (which is exactly how fish are designed, 664^a19–24). That would remove the need for an oesophagus and thereby eliminate the choking problem entirely. But Aristotle argues that this way of configuring the body is not possible for a blooded animal furnished with lungs. First of all, in order for the lungs to work efficiently they must be connected to the mouth by means of an extended tube; hence the presence of the windpipe. It follows from this that animals with lungs must also have an oesophagus connecting the stomach to the mouth (664^a25–32). Second, all blooded animals must have a heart. The placement of the heart (which is of primary importance) makes it unavoidable that the windpipe will be situated in front of the oesophagus

²⁶ The question of how Aristotle thinks we go about determining which features of a thing are basic and thus do the constraining is beyond the scope of this paper. It is bound up with difficult questions about causal priority, essences, and the method for establishing first principles.

²⁷ I borrow this phrase from S. J. Gould and R. C. Lewontin, 'The Spandrels of San Marco and the Panglossian Paradigm: A Critique of the Adaptationist Programme', *Proceedings of the Royal Society of London*, 205 (1979), 581–98.

(665^a9–26). In order to ‘remedy the problem’ (*tēn phaulotēta . . . iatreuken*, 665^a6–8), Aristotle says, nature has devised a quick fix in the form of the epiglottis (in mammals) and a collapsible larynx (in birds and reptiles). Here, the awkward position of the oesophagus behind the windpipe is explained, not by the goal-directed actions of the formal nature, but by certain architectural constraints that are imposed on the construction of all blooded animals furnished with lungs. In this case the constraints themselves can be identified as the cause of the design flaw, while nature’s optimizing efforts are the cause of its remedy.

Although Aristotle will include features of a thing’s architecture in the definition of its substantial being (see n. 14), it is important to distinguish what I am calling ‘architectural constraints’ from those constraints rooted in its essence. We can see this by contrasting the way the length of a snake puts (formal) constraints on the number of legs it has with the way the physical dimensions of a fish put (architectural) constraints on the number and configuration of its fins (*PA* 4. 13). For example, Aristotle tells us that the width and flatness of a skate prevent it from having the typical four-fin configuration of other bony fish (696^a21–7).²⁸ Given this architectural constraint, it is impossible for nature to build a skate with four evenly placed fins. Instead, nature has given it a single fin stretching around the outer edge of its body as its primary means of propulsion. With architectural constraints, then, certain features of the animal’s basic body plan make other traits *physically* impossible. In cases where the constraint emerges from the very definition of a thing’s substantial being, certain designs become *analytically* impossible. Obviously nature could design a reptile that had a more proportionate body in order to accommodate four legs. But such a creature would not *be* a snake by definition.²⁹

²⁸ As mentioned, there is a question here about the method by which Aristotle goes about determining the causal priority among features, in this case why he treats the physical dimensions of the skate as the basic feature of its architecture that does the constraining. I shall leave that question to one side.

²⁹ The contrast can be made even more explicit by considering *PA* 4. 9, 685^b13–17. There Aristotle notes that, while most octopuses have two rows of suckers, the kind called *ἐλεδώνη* has only a single row: ‘This is because of the length and thinness of its (material) nature; for it is necessary [sc. given its physical dimensions] that the narrow tentacle have a single row of suckers. It is not, then, because it is best that it has this feature, but because it is necessary owing to the distinctive account of its being [διὰ τὸν ἴδιον λόγον τῆς οὐσίας].’ The constraining feature here is the narrowness of the arm. Although this feature happens to be in ‘the distinctive account of its

What the discussion of biological constraints makes clear is that Aristotle does not think of teleological causation in terms of extreme perfection (at least not in the sublunary world of material composites). In a perfect world snakes would be equipped with enough legs to allow them to move from place to place with ease, all mammals would be constructed without the need for an epiglottis, and ruminants would have horns as well as a full complement of teeth. But Aristotelian natures operate in a world that is replete with constraints. As a result of these constraints, the best possible forms often turn out to be worse than the best conceivable ones. In many cases various constraints conspire to make it virtually impossible to achieve absolute perfection.³⁰ For example, Aristotle argues that all blooded animals require some sort of internal skeleton as a support system. In designing sharks and rays, however, three constraints arise that impose limits on how nature can achieve that goal (with the following see *PA* 2. 9, 655^a23–8). On the one hand, the ‘more fluid’ (*hugroteran*) movement of sharks and rays requires a skeletal structure that is quite flexible (a functional constraint). On the other hand, the animal’s formal nature ‘cannot distribute the same excess materials to many different locations at once’ (a developmental constraint), and it must use up all the earthy material on the formation of its skin (a competing functional demand). So while solid bone might make for a better skeleton in the abstract, given these various constraints cartilage turns out to be *the best possible* material for the skeletons of sharks and rays.

As we have seen, Aristotle’s optimality principle states that the natures of living things *never* do anything in vain (*outhen poiei matēn*) but *always* (*aei*) select what is best for the substance from among the range of possibilities. This gives the optimality principle the character of a universal ‘law’ that governs all the actions of the formal nature. It follows that, if the development of some feature *X*

being’, it is operating as an architectural (rather than purely formal) constraint: having narrow arms makes more than one row of suckers physically impossible. In this case the constraint itself (rather than the optimizing actions of the formal nature) explains the trait in question. This contrasts with the discussion of the oesophagus in *PA* 3. 3. There the architectural constraint explained the existence of the design flaw (the awkward position of the oesophagus behind the windpipe), while the optimizing actions of the formal nature explained its remedy (the epiglottis/collapsible larynx). For a discussion of the octopus example see J. G. Lennox (trans. and comm.), *Aristotle: On the Parts of Animals I–IV* [*Parts of Animals*] (Oxford, 2001), 314.

³⁰ Gotthelf, *First Principles*, ch. 8, provides a complex illustration of this point.

is an intrinsic product of the formal nature, then *X* must be the best way of realizing that feature from among the possibilities.³¹ But this way of understanding the optimality principle appears to conflict with another teleological principle according to which nature does everything *either* because it is (conditionally) necessary *or* on account of the better (*GA* 1. 4, 717^a15–16).³² Aristotle takes these two alternatives to be mutually exclusive. For any feature *X*, if *X* is a product of the formal nature, then it is present *either* because it is necessary for performing some function *φ* *or* because it is better. By ‘better’ he means that *X* improves the execution of *φ* though it is not, strictly speaking, necessary for *φ*-ing. For example, the liver is necessary for all blooded animals because of the essential role it plays in processing nutriment (*PA* 3. 7, 670^a22–9; 4. 2, 677^a36–^b5). The kidneys, on the other hand, are not necessary for processing nutriment (you could build an animal without them), but having kidneys improves that function (*PA* 3. 7, 670^b23–7). According to this principle, explanations in terms of ‘the better’ are to be *contrasted with* explanations that appeal to conditional necessity.

But this does not actually conflict with my reading of the optimality principle as a universal law of biological form, since the *GA* 1. 4 principle (I shall argue) is not contrasting conditional necessity, on the one hand, with optimization, on the other. For ‘the better’ in the *GA* 1. 4 principle does not capture the same idea as ‘the best’ in the optimality principle.³³ This is clear from the fact that optimality reasoning cuts right across the *GA* 1. 4 distinction.

³¹ Note that this does not mean that Aristotle thinks every feature of the organic body has been optimized for the performance of some function; Aristotle is no Panglossian. For the formal nature is not the *per se* cause of every feature in a living thing. Some features are incidental by-products of the actions of formal natures (e.g. bile: *PA* 4. 2, 677^a12–18), others the result of necessary changes rooted in the material nature (e.g. *GA* 5. 1–7; see M. Leunissen and A. Gotthelf, ‘What’s Teleology Got to Do with It? A Reinterpretation of *Generation of Animals* V’ [*GA* V], *Phronesis*, 55 (2010), 325–56; repr. in Gotthelf, *First Principles*, ch. 5), while others may be the direct result of biological constraints (e.g. the suckers on the *ἐλεδώνη*). Since none of these features is the *per se* result of the goal-directed activities of the formal nature, they fall outside the scope of Aristotle’s optimality principle.

³² *εἰ δὲ πᾶν ἢ φύσις ἢ διὰ τὸ ἀναγκαῖον ποιεῖ ἢ διὰ τὸ βέλτιον, καὶ τοῦτο τὸ μόνον εἴη διὰ τούτων θάτερον*. I take *ἢ φύσις* here to refer to the formal nature of the animal in question.

³³ Lennox, *Philosophy of Biology*, 221 n. 6, raises the issue but does not address it. Leunissen, *Explanation and Teleology*, 133, recognizes that ‘the better’ and ‘the best’ are not equivalent notions. Nevertheless, she contrasts appeals to optimization with appeals to conditional necessity (119). Compare Gotthelf, *First Principles*, 12 n. 18, 174 n. 56, 235–6.

First take conditional necessity. In order to execute the function of chopping, an axe must be made of some hard material; that type of material is conditionally necessary for being an axe. But this general requirement is satisfied, albeit to different degrees, by a whole range of materials such as iron, bronze, or diamond. Supposing the art of the blacksmith is also governed by an optimality principle, we should expect the expert blacksmith to select the best materials for chopping from among that range of possibilities. In this way explanations in terms of conditional necessity are fully compatible with, rather than opposed to, explanations that employ optimality reasoning. Something can *both* be necessary for doing ϕ *and* be (or not be) the optimal way of executing ϕ .³⁴ Now take the other side of the contrast. To say that some part is present 'on account of the better' means that it is not necessary for doing ϕ but it improves the animal's ability to do ϕ . For example, while animals can survive without kidneys, having them improves liver function by facilitating its ability to concoct the blood. In this way nutrition works better with kidneys. But notice that there may be a range of better and worse ways of improving liver function. Since nature always does what is best for each substance from among the range of alternatives, then we can explain why animals have kidneys by showing that a mechanism for filtering the blood is in fact *the best way* of improving liver function.

If this is right, then the principle that nature does nothing in vain but always what is best (optimal) for the organism given the range of possibilities is distinct from, and even complementary to, the principle that nature always does something either because it is necessary or because it is better. And if it is true that nature does *nothing* in vain but *always* what is best for the organism, then the design of both its necessary parts (e.g. the liver) and what Leunissen calls its 'subsidiary' (e.g. kidneys) and 'luxury' parts (e.g. horns)—those that are present on account of the better—will equally be subject to principles of optimization.

³⁴ The existence of females is an example of something that is *both* conditionally necessary for reproduction *and* the best way of ensuring the persistence of species from among the available alternatives. See C. Witt, 'Aristotle on Deformed Kinds', *Oxford Studies in Ancient Philosophy*, 43 (2012), 83–106.

4. Nature's design space

As we have seen, optimality reasoning requires determining what is best 'from among the possibilities concerning each kind of animal'. But how does Aristotle think the student of nature goes about determining that range? How do we come to know which modifications are in fact possible for a given trait? Although Aristotle is not explicit about this, I think that there is enough evidence to allow us to make some reasonable conjectures.

According to one interpretation, call it the inductive reading, the range of what is possible for a given trait is determined empirically by observing the range of actual variation exhibited by the wider kind.³⁵ For example, the range of possible dental arrangements for a blooded animal corresponds to the various ways that teeth are actually arranged in all the blooded animals taken collectively. Since no blooded animal has both serrated teeth and tusks, it follows (according to this reading) that this combination is not among the range of possibilities. On this interpretation Aristotle conceives of the range of possibilities in purely empirical terms: 'Thus what is possible within a kind is established inductively, through a study of the ways, to use our example, teeth are arranged in the various kinds of toothed animals.'³⁶

There is at least one example in the corpus that points towards the inductive reading. In *PA* 4. 5 Aristotle considers why sea urchins have five eggs symmetrically placed around their bodies that line up with each of their five teeth and stomachs. He first works out that sea urchins must have an odd number of eggs. As the inductive reading predicts, he then rules out any odd number greater than five on the grounds that no other member of the wider kind has them arranged in that way:

The egg cannot be continuous, since it does not occur in that way in any of the other hard-shelled animals; it is always on one side of the disk only.

³⁵ This reading is defended by Lennox, *Philosophy of Biology*, e.g. 207, 214, and Leunissen, *Explanation and Teleology*, e.g. 132–3. Although Leunissen explicitly endorses Lennox's reading, her interpretation turns out to be much less restrictive. For she allows for a notion of 'design space' (61) that includes more than what is actually realized in the world. On her reading, the range of possibilities also includes 'hypothetical' designs (126) that are known by means of 'thought experiments' (62). This is compatible with the interpretation I defend below.

³⁶ Lennox, *Philosophy of Biology*, 214.

Accordingly, since this part is common to all of them while the spherical body is peculiar to the sea urchin, it is not possible for the eggs to be even in number. If they were, they would have to be arranged in opposition because both sides would have to be symmetrical, and then there would be eggs on both sides of the circumference. But this arrangement is not found in any other hard-shelled animal. (680^b 14–21)

Aristotle concludes that sea urchins must have exactly five eggs because that is the best arrangement from among the remaining possibilities. As this passage makes clear, those possibilities are established (at least in part) by appealing to the observable range of variations among the members of the wider kind.

However, there are at least two other passages that suggest Aristotle is not thinking of the range of possibilities purely in terms of 'empirical possibilities' as characterized by the inductive reading. The first comes in *PA* 3. 2, where Aristotle takes up Momus' criticisms in one of Aesop's fables.³⁷ According to the version of the story that Aristotle appears to know, Zeus fashioned a bull and asked Momus to judge his handiwork. Momus was so consumed with jealousy that he blasted Zeus for failing to put horns on the bull's shoulders, whence it could deliver the strongest blows. In defence of the bull's design, Aristotle launches into the following counter-attack:

Nature also acted correctly in making the structure of the horns on the head, rather than acting like Aesop's Momus, who blames the bull because it does not have its horns on its shoulders, from where it could produce the strongest blows, but on the weakest part, its head. Momus made these accusations through a lack of sharp insight. For just as horns, if they had been placed anywhere else on the body, would provide weight while not being useful and even be a hindrance to many of its functions, so too would they be useless if placed on the shoulders. Indeed, one should target not

³⁷ Lennox dismisses this counter-example on the grounds that it is a criticism of a fable writer, not a natural philosopher, and so cannot be taken seriously (J. G. Lennox, 'Teleology in Scientific Explanation: Commentary on Henry and McDonough', presented at the annual meeting for the American Philosophical Association (Boston, 2010)). However, at *Phys.* 2. 2, 194^a31–4, Aristotle likewise refers to the views of a poet as a way to make a serious philosophical point (see also *Phys.* 2. 8, 198^b18). Moreover, Phil Horky suggests that it would not have been unusual for Aristotle to have taken Aesop's views seriously (personal communication). They would certainly have been considered a legitimate source of reputable opinions—that is, as part of the *endoxa*. Whether or not Aristotle takes Aesop's view as a serious challenge here, it is clear that his explanation for why bulls have horns on their heads is meant to be taken seriously. And that is sufficient for my point.

only from where the strongest blows would come but also from where they would be further forward. So, since bulls do not have hands and it is impossible for horns to be on the feet, and further if they were on the knees they would prevent them from bending, they must have horns just as they in fact do—on the head. And at the same time, the body's other movements are also naturally most unimpeded. (*PA* 3. 2, 663^a34–^b12)

Although Aristotle does not invoke the optimality principle here, this passage is a nice example of the use of optimality reasoning. It is one of the few places where Aristotle explicitly considers a range of options, rules some out as not being possible, and then shows how among the remaining possibilities the one selected is clearly the best.

The passage considers several different locations for placing horns on a bull: head, shoulders, knees, feet, and hands. The last two options are both excluded from the range of what is possible for a bull (for reasons that need not concern us here). But shoulders and knees are clearly treated as being among the possibilities. Aristotle rules these options out, not because they are impossible, but because they are suboptimal. This is clearly a problem for the inductive reading. Since there are no horned animals that actually have horns on their shoulders or on their knees, the inductive method would have led Aristotle to conclude that these locations are not within the range of what is possible for a bull. For induction tells us that horns are never located in those spots.³⁸ But that is not what Aristotle does here. In this example what is possible for a bull is not established inductively through a careful study of the ways that horns are actually arranged in the various kinds of horned animals. Instead, Aristotle speculates about a set of *hypothetical* designs and then offers reasons for why nature did not select those alternatives.

The snake example offers further evidence that Aristotle's method of determining what is possible for a given trait is not entirely an empirical matter but makes use of reasoning that is, in some sense, independent of experience. Aristotle tells us that having more than four limbs is not among the range of possibilities for a snake because no blooded animal can move at more than four points of motion (*IA* 8, 708^a12–14). When we turn to *IA* 6 we discover that this claim is itself derived from universal principles that

³⁸ Compare Lennox, *Philosophy of Biology*, 214.

apply to all things that move from place to place by means of limbs (*IA* 6, 707^a6–16). The relevant argument in *IA* 6 is complicated, but it appears to have the following structure:

- (P1) Two of the primary dimensions of a moving body, the superior/inferior and the right/left, are connected to one another through a common origin in the centre of the body, which is the source of their movement (this common origin is the heart in blooded animals).
- (P2) This primary origin of motion must be located at some fixed distance from the proximate sources of motion in the limbs (which in animals are the joints: see *De motu* 1).
- (P3) The primary origin of motion must be more or less the same distance from each of those proximate sources of motion.

From these three principles Aristotle derives the conclusion:

Since these conditions apply exclusively or most of all to blooded animals, it is clear that it is not possible for any blooded animal to move by more than four points of motion and that if some animal naturally moves by only four points, it must of necessity be blooded. (707^a19–24)

Although Aristotle goes on to say that this conclusion is confirmed by what we observe among blooded animals (707^a23–708^a7), the conclusion itself is not something that is known by experience. What is possible for a snake is established, not strictly by appealing to observations of the wider kind, but by showing how it follows from general principles concerning the physical dimensions of the animal's body.³⁹

The lesson I wish to draw from these two examples is the following. While Aristotle is not explicit about how he thinks the student of nature goes about determining the range of possibilities for a given trait, it is clearly not simply a matter of reading off that

³⁹ It is true that Aristotle establishes *the fact* that no blooded animal moves at more than four points (the *ᾧτι*) inductively by surveying various animal kinds (cf. *IA* 1), but the *reason why* it is not possible (the *διότι*) is grasped by means of this rational argument. Note that, while the universal principles that figure in such arguments may themselves be established inductively (see *De iuv.* 469^a23–^b1, translated below), that is not the issue here. What is at issue is the nature of our grasp on the conclusion of the argument, which concerns the range of what is possible. Frede characterizes what is known by deduction from first principles as '*a priori*' knowledge (M. Frede, 'Aristotle's Rationalism', in M. Frede and G. Striker (eds.), *Rationality in Greek Thought* (Oxford, 1996), 157–74 at 158). While I agree with this characterization, I refrain from using that language here.

range directly from the observed variations exhibited by some wider kind. Instead, determining what is possible requires a mixture of empirical and rationalist considerations. In some cases the natural scientist might need to extend beyond what is observable and use her imagination to consider hypothetical designs that are not realized by any actual species (as in the horns case). In others she may need to rely on arguments where what is and is not possible is established through reasoning that proceeds, in some sense, independently of experience (as in the snake example). Of course Aristotle does not go as far as Plato in treating optimality reasoning as an exercise of pure thought where one simply attempts to reconstruct, entirely independently of experience, the pattern of reasoning that would have gone into something's optimal design. One of the main reasons, we have seen, is that Aristotle thinks nature's ability to optimize traits is largely restricted by the existence of various biological constraints. And knowing which constraints are operative on a given organism is not something that can be worked out from the armchair. These are facts that depend on knowledge that can be acquired only by carefully studying living things in their natural environments.

One might object that the contrast with Plato here is unfair given the earlier discussion about constraints in the *Timaeus*. The idea that Plato treats optimality reasoning as an exercise of pure thought was part of Sedley's claim that the *Timaeus* represents Plato's ongoing attempt to 'intellectualize' natural science. However, if Johansen is right about the existence of material constraints, then surely Plato would agree with Aristotle that knowing which constraints are operative on a given organism cannot be worked out entirely from the armchair. For facts about the necessary properties of matter will depend on knowledge that can be acquired only through an empirical study of the world. However, I do not think this objection is decisive. For Sedley could accept that the necessary properties of matter set prior constraints on *Nous*'s design space and simply argue that Plato thought we could deduce those properties from *a priori* knowledge of the geometrical figures that constitute the simple bodies (cf. *Tim.* 53 B 7–69 A 5).⁴⁰

⁴⁰ Even if Plato did think that our knowledge of material constraints depended in some sense on experience, we could still agree with Sedley that in the *Timaeus* optimality reasoning is seen as an attempt to reconstruct the pattern of reasoning that went into the world's design by the creative *Nous*. It is just not a purely *a priori*

5. The role of optimization in natural science

I now want to turn to my final question about the role of the optimality principle in Aristotle's natural science. There are two main interpretations canvassed in the literature. In *IA* 2, 704^b12–18, Aristotle tells us that the optimality principle is among those things that must be laid down as suppositions (*hupothemenois*) of natural enquiry. Lennox argues that 'supposition' here should be taken in the technical sense of *Post. An.* 1. 2.⁴¹ There we are told that suppositions are a kind of postulate (*thesis*) which, along with definitions, are included among the first principles of a demonstrative science. And such principles, we are told, are 'among the premisses' of a demonstration (*Post. An.* 1. 10, 76^b35–9; 77^a10–12). If the optimality principle is a supposition in this technical sense, Lennox argues, then we should expect it to function as a premiss in demonstrations.⁴² In contrast to this, Leunissen argues that teleological principles, such as 'nature does nothing in vain', do not figure in scientific explanations properly speaking. Instead, their function is purely heuristic in the sense that they *point us towards* those causally relevant features that are cited in proper explanations.⁴³ Like all heuristic devices, Leunissen argues that such teleological principles can be kicked aside once those causal features have been found so that the ultimate explanation can be formulated 'without the teleological principle figuring as one of its premisses'.⁴⁴ On the account I shall defend, the optimality

exercise that proceeds entirely independently of experience. While this would force us to give up the idea that the *Timaeus* is an attempt at 'intellectualizing' physics (as Sedley claims), this does not affect my overall thesis about Aristotle's *central* revisions to the Platonic conception of optimality (see below, sect. 6).

⁴¹ Lennox, *Philosophy of Biology*, 211–15.

⁴² For problems with the use of 'premiss' here see Leunissen, *Explanation and Teleology*, 122 n. 25. Although I am sympathetic to Leunissen's claim that the optimality principle does not have the right structure to function as a genuine premiss in an Aristotelian syllogism, the reading I defend below does not turn on whether or not explanations that feature the optimality principle meet the formal requirements for proper demonstrations. I return to this question below.

⁴³ Leunissen, *Explanation and Teleology*, 125–7, discusses the teleological principle in *GA* 1. 4 as a paradigm example.

⁴⁴ Leunissen, *Explanation and Teleology*, 121; see also § 4.2, esp. 129–35. By calling teleological principles 'heuristic' devices Leunissen is not reviving the so-called Kantian reading of Aristotle's teleology (e.g. W. Wieland, 'The Problem of Teleology', in J. Barnes, M. Schofield, and R. Sorabji (eds.), *Articles on Aristotle*, i. *Sci-*

principle actually plays both of these roles in Aristotle's natural science. According to this pluralist reading, while Aristotle does use optimality reasoning as a heuristic device for identifying the causally relevant features of natural phenomena, there are clear examples where the fact that nature does what is best for the substance is treated as one of those causally relevant features. In those cases the optimality principle must be cited in a causal explanation for the phenomenon in question.

There is at least one example in the biological works where the optimality principle is clearly used as a heuristic device. In *GA* 2. 5 Aristotle raises the puzzle about why males exist in addition to females (741^b4–5). He invokes the optimality principle to help resolve this puzzle: if females could generate on their own, then males would exist in vain; nature does nothing in vain; therefore, males must make some contribution to generation. But notice that this does not explain why males exist. Knowing that nature does nothing in vain allows us to infer *that* males make some necessary contribution to generation. But this is only a preliminary step towards the ultimate explanation. The ultimate explanation must identify the cause for the sake of which males exist, which picks out their necessary function (they provide sensory soul: 741^b6). All the optimization principle does here is help us to see that males must make *some* contribution to generation; it does not tell us what that contribution is. In this example, then, optimality reasoning clearly forms part of a chain of inferences leading to the identification of the primary cause of the explanandum. But since the principle does not state that cause, it will not be part of the actual explanation.

There is something important to be gleaned from Leunissen's insights about the heuristic role of teleological principles in Aristotle's

ence (London, 1975), 141–60). On that reading, Aristotle thinks it is useful to look at nature 'as if' it was governed by final causes, since adopting the teleological perspective helps to identify the real (i.e. material-efficient) causes of things. Since Aristotle thinks final causes have no ontological significance (on the Kantian reading), natural science can dispense with the crutch of teleology once those true causes have been found. Leunissen denies that this is Aristotle's view (e.g. 112). On her reading, Aristotle sees natural science as a search for the ultimate causes of natural phenomena, which include final causes. Those final causes have real ontological force and constitute an ineliminable feature of Aristotle's world. Living things *really are* teleologically organized systems whose development and functioning are controlled by the goal-directed actions of their formal natures. It is only the *teleological principles*, such as 'nature does nothing in vain', that Leunissen thinks play a heuristic role in Aristotle's natural science. For a thorough critique of the Kantian reading of Aristotle see Johnson, *Teleology*, 182–7.

natural science, especially when compared with Plato. For Plato the universe really is designed by a Divine Craftsman who deliberated about what was best for each thing and then, with the help of the lesser gods, put those plans into action. Within this framework optimality reasoning is a literal attempt to reconstruct the chain of inferences that the Demiurge followed in working out those designs. While Aristotle agrees with Plato that optimality reasoning is a useful strategy for discovering causes, such reasoning does not represent any actual deliberation process on the part of nature. For the natures of living things do not deliberate (*Phys.* 2. 8, 199^b26–30). At the same time it would be a mistake to suppose that Aristotle viewed optimality reasoning as purely heuristic. Aristotle thinks that the inner sources of change that regulate the growth and development of living things *really do* operate according to principles of optimization, a fact that makes a real difference to how the world turns out. While Aristotle's use of design language may be completely metaphorical, his claim that the natures of living things never do anything in vain but always what is best for the substance most certainly is not.⁴⁵

The problem with Leunissen's reading is that there are several examples in Aristotle's biological works where the optimality principle clearly plays an explanatory role. In those cases the optimality principle is not simply a heuristic device that can be kicked aside once the causally relevant features have been identified. The fact that natures are optimizing agents *is* one of those causally relevant features and so cannot be eliminated from the explanation without loss of crucial explanatory content. This seems to conform better to Lennox's reading. Let me offer two examples.⁴⁶

For the first example we can return once again to Aristotle's explanation for why snakes have no legs.⁴⁷ As we have seen, Aristotle explicitly identifies the optimality principle as a causal factor (*aitia*) in the explanation for the absence of legs in snakes. Indeed, it is dif-

⁴⁵ Leunissen, *Explanation and Teleology*, 119, agrees with this much: 'I take it that the different kinds of actions ascribed to these formal natures reflect the operations of different kinds of causality that typically obtain in the production of animals and their parts. Teleological principles are thus no mere metaphors; they all carry ontological force.'

⁴⁶ Of these two examples, Leunissen discusses only the first (*Explanation and Teleology*, 131–2). See also *GA* 2. 6, 744^a34–^b1, and the examples discussed in Lennox, *Philosophy of Biology*, 211–15.

⁴⁷ Cf. Lennox, *Philosophy of Biology*, 218.

difficult to see how the explanation would still be explanatory if it did not include reference to that principle as a cause. Leunissen correctly identifies the fact that snakes have elongated bodies and the fact that having four legs would be pointless as being relevant to the explanation. But these facts alone are not sufficient to explain why snakes do not have any legs (they might still have had two or four). We also need to know that the formal natures of snakes do nothing in vain but always what is best for the animal and that having no legs is the best design for a snake given the possibilities.

The other example comes from *De iuventute*. In *De iuv.* 2 Aristotle claims that the *archē* of the soul is located in the mid-section of the organism between its upper and lower parts. This, he says, can be established both through perception (*kata tēn aisthēsin*) and according to reason (*kata ton logon*) (468^a20–3). With arguments that proceed *kata tēn aisthēsin* the conclusion is established inductively by appealing to what is observable. By contrast, with arguments that proceed *kata ton logon* the conclusion is established by showing how it follows of necessity from certain universal principles.⁴⁸ *De iuv.* 2–3 attempts to establish the proposition about the *archē* of the soul by drawing on observable data gathered from the empirical study of animals and plants, while *De iuv.* 4 provides additional support by appealing to different rational arguments. The first of these rational arguments explicitly invokes the optimality principle as one of its premisses:

Thus it is clear from what has been said, in accordance with the observed facts, that both the origin of the sensory part of the soul and those connected with growth and nutrition are located in this and in the middle of the three parts of the body. This is also in accordance with reason because we see that in every case nature does that which is best [*τὸ κάλλιστον*] from among the possibilities: the two parts of the body (that which prepares the ultimate nutriment and that which receives it) would each accomplish its proper function most if each origin was in the middle of the substance; for then the soul will be close to both parts, and the central position of such a capacity will be in a position of control. (*De iuv.* 4, 469^a23–^b1)

As with the snake example, the optimality principle forms an in-

⁴⁸ See e.g. *MA* 1, 698^a11–13; *Meteor.* 4. 1, 378^b13–26; *PA* 2. 1, 646^a29–30; *GA* 1. 20, 729^a20–4; 2. 4, 740^a4–5. See also R. Bolton, ‘Two Standards of Inquiry in Aristotle’s *De caelo*’, in A. C. Bowen and J. Wilberg (eds.), *New Perspectives on Aristotle’s De caelo* (Boston, 2009), 51–82. I disagree with Bolton’s main thesis that the distinction in question maps onto the distinction between scientific and dialectical arguments.

eliminable part of the explanation for why the *archē* of the soul is located in the mid-section of the organism between its upper and lower parts. To see this, consider how someone like Empedocles would explain the phenomenon. For Empedocles, the fact that the *archē* of the soul is located in the middle of the body rather than in some other location is merely accidental and the result of chance. Of course he could agree with Aristotle that the upper and lower parts of an animal happen to function best when the *archē* of the soul is located in the middle. But that fact is irrelevant to the explanation.⁴⁹ Thus, Aristotle is justified in drawing the inference that the *archē* of the soul is located in the middle region *because* that is the best location for it to be, only if it is true that the formal natures of living things are optimizing agents that always do what is best for the substance given the range of possibilities.⁵⁰ Without citing the optimality principle as part of the explanation, Aristotle's teleological account of the soul's origin loses its explanatory force.

It is clear from the above discussion that Aristotle thinks the optimality principle can play different roles in natural science. In some cases optimality reasoning is a useful heuristic that helps identify the causally relevant features cited in the explanation of some natural phenomenon, even though the optimality principle itself does not form part of the ultimate explanation. However, as we have seen, there are also cases where the fact that nature does what is best for each substance *is* among the causally relevant features and so cannot be eliminated from the account without loss of crucial explanatory content.

This does not completely vindicate Lennox's reading, however. The debate between Lennox and Leunissen has to do with the role of the optimality principle in demonstration (*apodeixis*). According to Lennox, optimality reasoning is a special form of demonstration in which the optimality principle functions as one of its premisses. While Leunissen agrees that proper explanations in biology must be demonstrative in form, she denies that explanations that invoke

⁴⁹ Likewise in the case of snakes, Empedocles might say that snakes lose their legs owing to some accident during development (compare *PA* 1. 1, 640^a19–24). The fact that they happen to move better without them is merely a fortuitous outcome and not part of the reason why snakes lack legs.

⁵⁰ Compare the last sentence of *LA* 2, 704^b12–18: 'Nature does nothing in vain but always what is best for the substance from among the possibilities concerning each kind of animal; *for this reason, if it is better this way, then it is that way and being in that state is in accordance with nature.*'

teleological principles could meet the formal requirements that the *Analytics* places on proper demonstrations. More specifically, she denies that such principles have the right structure to function as genuine demonstrative premisses.⁵¹ Thus, she concludes, such teleological principles could not be part of scientific explanations properly speaking.

While I am sympathetic to Leunissen's concerns here, the focus on the formal requirements of demonstration is a red herring. The important issue is not whether explanations that feature the optimality principle could be reconstructed in demonstrative form but whether the fact that nature does nothing in vain but always what is best for the substance is one of the causally relevant features of the phenomenon in question. If it is, then a causal explanation of that phenomenon must make reference to the optimality principle. Now it is obvious to anyone who reads Aristotle's biological works that the causal explanations on offer are not demonstrative in form.⁵² Although Lennox believes that many of those explanations could be reformulated in ways that meet the formal requirements of proper demonstrations, he suggests that important content may be lost in the process of converting them into the logical syntax of a demonstrative syllogism.⁵³ Thus, even if Leunissen is *technically* right that we could not reconstruct explanations that feature the optimality principle in proper demonstrative form (and I am not convinced she is), it does not follow that Aristotle thinks the optimality principle does not form part of any causal explanations for natural phenomena and must therefore be part of some preliminary stage of discovery. The fact that nature does nothing in vain but always what is best for the substance might simply be among those causally relevant features that get lost in the process of syllogizing those explanations.⁵⁴

⁵¹ Leunissen, *Explanation and Teleology*, 122.

⁵² For doubts that explanations in biology could be proper demonstrations see J. Barnes, 'Aristotle's Theory of Demonstration', *Phronesis*, 14 (1969), 123–52, and G. E. R. Lloyd, *Aristotelian Explorations* (Cambridge, 1996), ch. 1. For replies see Lennox, *Philosophy of Biology*, 1–6, and Gotthelf, *First Principles*, ch. 7. My reading is meant to be neutral on this issue.

⁵³ Lennox, *Philosophy of Biology*, 6.

⁵⁴ Leunissen allows that teleological principles might be 'part of the partial or informal explanation of some phenomenon' and thus part of 'the larger explanatory account' (*Explanation and Teleology*, 122). But she does not say what that entails. If all she means is that *technically* the formalized demonstration will not feature the optimality principle, then that is less interesting. Explanations of natural phenomena are supposed to give us knowledge of their causes. And the fact that nature

6. Two conceptions of optimality

In this paper I have attempted to draw attention to Aristotle's use of optimality reasoning as an important dimension of his natural teleology, something (I have suggested) he inherited from Plato. As we have seen, both Plato and Aristotle view the natural world as the product of an optimizing agent, and both see this assumption as licensing a certain pattern of reasoning that appeals to a conception of 'what is best' (*to ariston*). This shared commitment to optimality reasoning highlights an important continuity between Platonic and Aristotelian teleology. Despite this general agreement, however, it would be a mistake to think that Aristotle simply took over Plato's use of optimality reasoning without significant modifications. In this section I would like to draw out more explicitly two key differences in the way Plato and Aristotle understand the use of optimality in natural science.

The first major difference concerns the scope of their respective optimality principles. In the *Phaedo* Socrates extends the notion of optimality to the whole cosmos. At 98 B 1–4 he says: 'Once he [Anaxagoras] had given the best for each as the cause for each and the general cause of all, I thought he would go on to explain *the common good* for all, and I would not have exchanged my hopes for a fortune.' This is echoed in *Laws* 10, where the Athenian Stranger attempts to convince Clinias of the thesis that the universe has been arranged with an eye to the good of the whole cosmos and that its individual parts (including Clinias himself) have each been created for the sake of that whole:

The supervisor of the universe has arranged everything with an eye to its preservation and excellence, and its individual parts play appropriate active

does nothing in vain but always what is best for the substance is among the causes of certain natural phenomena and so must be cited in a complete explanatory account of them. If Lennox is right about the loss of explanatory content in converting such explanations into proper demonstrative form, then the formal demonstration that drops the optimality principle will actually turn out to be less explanatory than the informal explanation that includes it. For example, the demonstration of the fact that snakes have no legs would contain less causal information (and therefore be less explanatory) than the informal explanation we get in *IA* 7 that includes as a cause (*αἰτία*) of that phenomenon the fact that the formal natures of snakes do nothing in vain but always what is best for the substance from among the possibilities. I do not see how this can be reconciled with Leunissen's claim that teleological principles serve a purely heuristic role in Aristotle's natural science.

or passive roles according to their various capacities. These parts, down to the smallest details of their active and passive functions, have each been put under the control of ruling powers that have perfected the minutest constituents of the universe. Now then, you perverse fellow, one such part—a mere speck that nevertheless constantly contributes to the good of the whole—is you, you who have forgotten that nothing is created except to provide the entire universe with a life of prosperity. You forget that creation is not for your benefit; you exist for the sake of the universe. Every doctor, you see, and every skilled craftsman always works for the sake of some end product as a whole. He handles his materials so that they will give the best results in general, and he makes the parts contribute to the good of the whole, not vice versa. But you're grumbling because you don't appreciate that your position is best both for the universe and for you, thanks to your common origin. (*Laws* 10, 903 B 5–D 1, trans. Saunders, modified)

For Plato, then, in order to explain why things are the way they are we need to consider not only what is best relative to each individual but also what is best relative to the whole cosmos.

Sedley has argued that Aristotle, too, thinks of the universe as an organized whole endowed with a nature of its own.⁵⁵ This cosmic nature, Sedley argues, is something over and above the natures of its individual parts (animals, plants, etc.). Sedley's main evidence for this reading comes from a controversial passage at the start of *Metaphysics A* 10:

We must consider also in which way the nature of the whole [*τὴ τοῦ ὅλου φύσις*] contains the good and the best—whether as something separated and by itself, or as its arrangement. Or is it in both ways, like an army? For an army's goodness is in its ordering, and is also the general. And more the general, since he is not due to the arrangement, but the arrangement is due to him. All things are in some joint-arrangement, but not fishes, fowls and plants all in the same way. And the arrangement is not such that nothing has any relation to anything else. They do have a relation: for all things are jointly arranged in relation to one thing. But it is like in a household, where the free men have least licence to act at random, but all or most of what they do is arranged, while the slaves and beasts do little for the common good and act mostly at random: for that is the sort of principle that each one's nature is. I mean, for example, that at least each of them must necessarily come to be dissolved; and there are likewise other things in which all participate for the whole. (*Metaph. A* 10, 1075^a 11–25, trans. Sedley)

⁵⁵ Sedley, *Creationism*, 194–204; id., 'Teleology: Aristotelian and Platonic' ['Aristotelian and Platonic'], in J. G. Lennox and R. Bolton (eds.), *Being, Nature, and Life in Aristotle* (Cambridge, 2010), 5–29; id., 'Is Aristotle's Teleology Anthropocentric?' ['Anthropocentric'], *Phronesis*, 36 (1991), 179–96.

Sedley takes the reference to 'the nature of the whole' to pick out a cosmic nature that belongs to the universe as a whole and embodies its good. This cosmic nature, Sedley argues, is prior (and therefore irreducible) to the natures of the individual organisms, since the latter are parts of the former.⁵⁶

It is entirely possible that Aristotle recognized more inclusive individuals above the level of particular organisms and that these more inclusive individuals might have 'natures' of their own.⁵⁷ However, we must be careful about how we understand this idea. Suppose the reference to nature in the *Metaphysics* passage does pick out the nature of the whole cosmos. In that case there is no doubt that Aristotle is referring to the order and structure displayed by the universe and not to some cosmic agent that imposes that order and structure on it like Plato's Demiurge.⁵⁸ In Aristotle's system God (the analogue of the general in this passage) is responsible for the orderly arrangement of the universe, not as an efficient cause, but as a final cause. More specifically, God is a cause of that arrangement as an object of desire. All natural bodies, from the elements to animals and plants to the heavenly bodies, in some sense 'desire' to be like the divine. And when the activities of all these goal-directed substances are each directed towards the same end (imitation of God), the result is a universe that exhibits order and arrangement.⁵⁹ Unlike Plato, Aristotle nowhere refers to this order and arrangement (the cosmic good) as the end for the sake of which its parts come to be and exist. Rather, the orderly arrangement of the whole cosmos is itself a consequence of, and

⁵⁶ See Sedley, *Creationism*, 198–200.

⁵⁷ See D. Henry, 'Organismal Natures', in J. Mouracade (ed.), *Aristotle on Life* (*Apeiron*, special issue, 41.3; 2008), 47–74 at 67–70. In the *Politics* Aristotle has no trouble seeing the *polis* as a natural whole that is ontologically prior to the citizens that are its parts (*Pol.* 1. 2, 1253^a19–30; cf. *Metaph.* Z 16). If this is right, then it may not be much of a stretch to imagine Aristotle treating the cosmos itself as complex individual endowed with its own cosmic nature.

⁵⁸ My reading depends on recognizing that Aristotle uses 'nature' in many ways. The two main candidates here would be: (1) nature as an inner principle of change and stasis *in* that to which it belongs primarily, in virtue of itself, and not incidentally (*Phys.* 2. 1, 192^b21–2; cf. *Metaph.* Z 7, 1032^a20–5; *GA* 740^b25–34; 770^b15–17); and (2) nature as 'the form and essence of a thing, which constitutes the end of the process of its generation' (*Metaph.* Δ 4, 1015^a10–11; cf. *GC* 335^b4–7). See also *PA* 1. 1, 641^a22–33. When Aristotle refers to 'the nature of the whole' in the *Metaphysics* A passage, he is almost certainly using 'nature' in a way that is akin to (2), albeit without the implication that the universe itself came to be.

⁵⁹ Leunissen, *Explanation and Teleology*, 46–7.

is thus explained by, the goal-directed activities of each particular natural substance aiming at its own individual good.

Thus, while I am not unsympathetic to Sedley's claim that Aristotle thinks the universe has a nature of its own (properly understood), what I do find objectionable is the idea that he thinks the parts of the universe are *co-ordinated* in such a way that their mutual interactions contribute to this cosmic good and, ultimately, the good of man.⁶⁰ There is so little evidence for this interactive dimension of Aristotelian teleology that I find it hard to believe this was a core feature of Aristotle's teleological perspective. If it were, then we should have expected Aristotle's biology to be driven by a deep interest in ecology and ecological relations. Yet, we find no traces of the concept of an ecosystem, no sign of the idea of 'the web of life', and very little attention to the ubiquitous co-adaptations that exist between living things.⁶¹ Sedley's main response to the absence of evidence for global teleology in Aristotle's biological writings is to say that while biology is 'squarely focused on individual bodily functioning', the global teleology is supplied by metaphysics.⁶² However, it is not that the biological works lack examples of such 'co-ordination' between species (see e.g. *PA* 4. 13, 696^b24–35; *GA* 3, 760^a31–^b1; 4. 10, 777^b16–778^a9). The problem is that there are so few of them. If Aristotle really did view nature through the lens of interactive teleology, then we would expect his biological works to be full of such examples. Moreover, it is not clear why a study of the co-ordination and interactions between the parts of nature—i.e. ecology—should belong to metaphysics and not to the science of nature itself. The absence of anything like an ecological perspective from Aristotle's science of nature and the fact that his biology is so 'squarely focused on individual bodily functioning' make much better sense if we assume that he rejected Plato's cosmic teleology.

Whatever we think of Sedley's interactionist reading of Aristotelian teleology, it remains that Aristotle's use of optimization in natural science does not in any way depend on the notion of a cosmic good. Aristotle tells us that nature does what is best for each particular kind of organism (*hekaston genos zōou*). And whenever he invokes this principle to explain the parts of living things, 'what is

⁶⁰ See Sedley, 'Anthropocentric', 180, and 'Aristotelian and Platonic', 24.

⁶¹ Contrast the ecologically rich perspective in Darwin's *Origin of Species*.

⁶² Sedley, 'Anthropocentric', 195–6, and 'Aristotelian and Platonic', 24–5.

best' is always understood in relation to that thing's own survival and well-being. Aristotle does not demand, as Plato clearly does, that we also show how each particular living thing contributes to the best possible state of the universe as a whole.⁶³

The second difference between Plato and Aristotle concerns the way in which each conceives of the optimizing agent itself. As we have seen, Plato's optimizing agent is a Divine Craftsman who is characterized by rationality and imposes goodness on the world from outside (*Tim.* 29 A 5–B 1; 29 D 7–C 1; 46 C 7–E 6; *Laws* 10, 889 A 4–E 1; 892 A 2–C 7).⁶⁴ Aristotle, on the other hand, identifies his optimizing agent with nature, which is contrasted with intelligence (*nous*) and craft (*technē*) and defined as a principle of change *in* that to which it belongs primarily, in virtue of itself, and non-incidentally (*Phys.* 2. 1, 192^b20–3).⁶⁵ More specifically, I have suggested that the 'nature' that does nothing in vain but always what is best for the substance is merely a generalization over the formal natures of particular natural substances. Obviously Aristotle still owes us an answer to the question of how the natures of living things manage to bring about their ends without intentions and desires. Unfortunately, he never actually addresses this problem anywhere in the extant corpus. However, I think he has the resources to do so. While a full defence of this is not possible here, to close this paper let me try to sketch out what I think that account might look like.⁶⁶

⁶³ Moreover, I have argued that Aristotle limits the optimality principle to the goal-directed activities of an organism's formal nature. And since not all features of a living thing are due to its formal nature, not every feature of the organic body will have been optimized for the performance of some function (see n. 28). Thus, Aristotle not only restricts the optimality principle to living things, he restricts it to certain features of living things.

⁶⁴ On the separateness of the Demiurge from the physical cosmos see Johansen, *Natural Philosophy*, 79–83, and Broadie, *Nature and Divinity*, ch. 1.

⁶⁵ Johansen, *Natural Philosophy*, 76–8, identifies the Demiurge of Plato's *Timaeus* with craftsmanship (*technē*) itself rather than a craftsman endowed with intelligence and forethought. On this reading, the gap between Plato and Aristotle becomes narrower than suggested here. On Johansen's reading, the difference between their respective optimizing agents would lie simply in the external/internal distinction.

⁶⁶ For an alternative account see Leunissen and Gotthelf, 'GA V', 344–7, and Leunissen, 'Crafting Natures: Aristotle on Animal Design', in G. Dicker (ed.), *Annual Proceedings of the Center for Philosophic Exchange* (SUNY Brockport, 2012), 28–51. The following takes its lead from the account of Aristotelian natures defended by Alexander of Aphrodisias ap. Simplicius in *Phys.* 310. 25–311. 1 Diels (cf. Alex. Aphr. in *Metaph.* 103. 37–104. 1, 349. 7–17 Hayduck). For a discussion of Alexander's reading see D. Henry, 'Embryological Models in Ancient Philosophy', *Phronesis*, 50 (2005), 1–42 at part 2.

Although many of the explanations in Aristotle's biological works make use of the metaphor of a demiurgic nature 'fashioning' animals and their parts like a craftsman, Aristotle could cash in the metaphor for the language of causal powers (*dunameis*). According to the account in *Metaphysics* Θ 1–5, causal powers come in two kinds: rational and non-rational powers (*Metaph.* Θ 2, 1046^a36–^b2). Rational powers are capacities to produce contrary effects (for example, the art of medicine is a capacity to produce health and disease). As such, Aristotle argues, contact with a suitable patient is necessary but not sufficient to trigger the power. There must also be a deliberate decision on the part of the agent to bring about one or the other of its effect (1048^a1–15).⁶⁷ Non-rational powers, on the other hand, produce uniform effects (for example, the heating power of fire only has the capacity to produce heat, not cold) and so are triggered simply by the presence of the corresponding power. With non-rational powers, once agent and patient come into contact under the right causal conditions, their corresponding powers are activated straight away, resulting in a change that is determined by the character of their respective powers. No deliberate decision on the part of the agent is necessary.

There is some evidence that Aristotle thought the metaphor of a nature 'fashioning' animals was simply shorthand for a more complex account in terms of the activation of a series of non-rational powers. For example, at the end of *GA* 2. 4 Aristotle identifies the nature that constructs the parts of an animal with the active powers of its own nutritive soul (740^b34–741^a3). And in two places he compares generation to the sequence of automatic movements executed by a mechanical puppet: *GA* 2. 1, 734^b10–13; 2. 5, 741^b7–9. In the former passage we are told that the ability of these automatons to move of their own accord is due to the fact that each part contains a *dunamis* for motion. And such *dunameis* can only be non-rational powers; for the mark of an automaton is that its movements are not the result of rational decisions (cf. 740^b18–24). Because non-rational powers do not require a deliberate decision to activate them, but instead action occurs as soon as agent and patient

⁶⁷ This is why I think it is a dead end to search for Aristotle's answer to the problem at hand in his cryptic remark at the end of *Physics* 2. 8 that natural teleology does not depend on deliberation 'for even the art does not deliberate' (199^b26–30). Whatever Aristotle means by this, *Metaphysics* Θ 5 is clear that the exercise of a $\tau\acute{\epsilon}\chi\eta$, at least, requires a deliberate decision on the part of the agent that possesses that $\tau\acute{\epsilon}\chi\eta$.

come into contact, this would allow Aristotle to explain how the natures of living things manage to bring about their ends without having to attribute to them real psychological states. Thus, to say that nature does nothing in vain but always what is best for the organism is, then, just to say those *dunámeis* that make up its formal nature are co-ordinated in such a way that their mutual activation generates parts that are optimized for its particular way of life.⁶⁸

The University of Western Ontario

BIBLIOGRAPHY

- Barnes, J., 'Aristotle's Theory of Demonstration', *Phronesis*, 14 (1969), 123–52.
- Bolton, R., 'Two Standards of Inquiry in Aristotle's *De caelo*', in A. C. Bowen and J. Wilberg (eds.), *New Perspectives on Aristotle's De caelo* (Boston, 2009), 51–82.
- Broadie, S., *Nature and Divinity in Plato's Timaeus [Nature and Divinity]* (Cambridge, 2012).
- Charles, D., *Aristotle on Meaning and Essence* (Oxford, 2000).
- Cornford, F. M., *Plato's Cosmology* (London, 1937).
- Frede, M., 'Aristotle's Rationalism', in M. Frede and G. Striker (eds.), *Rationality in Greek Thought* (Oxford, 1996), 157–74.
- Gotthelf, A., 'The Place of the Good in Aristotle's Teleology', in J. J. Cleary and D. C. Shartin (eds.), *Proceedings of the Boston Area Colloquium in Ancient Philosophy*, 4 (1988), 113–39.
- , *Teleology, First Principles, and Scientific Method in Aristotle's Biology [First Principles]* (Oxford, 2012).
- Gould, S. J., and Lewontin, R. C., 'The Spandrels of San Marco and the Panglossian Paradigm: A Critique of the Adaptationist Programme', *Proceedings of the Royal Society of London*, 205 (1979), 581–98.
- Henry, D., 'Embryological Models in Ancient Philosophy', *Phronesis*, 50 (2005), 1–42.

⁶⁸ This does not imply that Aristotle thinks final causation is a mere heuristic device in the Kantian sense. For Aristotle will insist that species natures contain the *dunámeis* they do for the sake of the ends they bring about (see *Metaph.* Θ 8, 1050^a4–14). To ask what co-ordinated those *dunámeis* in the first place would be misguided, since the developmental capacities possessed by Aristotelian species are not the result of any process of evolution. That the natures of living things contain the sorts of *dunámeis* for parts that are optimized for their way of life is a basic feature of Aristotle's world, explained only (as a final cause) by reference to the contribution they make to the animal's survival and well-being.

- ‘Organismal Natures’, in J. Mouracade (ed.), *Aristotle on Life (Apeiron)*, special issue, 41.3; 2008), 47–74.
- Huby, P., ‘What Did Aristotle Mean by “Nature Does Nothing in Vain”?’ [‘Nothing in Vain’], in I. Mahalingam and B. Carr (eds.), *Logical Foundations* (Hong Kong, 1991), 158–66.
- Johansen, T. K., *Plato’s Natural Philosophy: A Study of the Timaeus–Critias* [*Natural Philosophy*] (Cambridge, 2004).
- Johnson, M. R., *Aristotle on Teleology* [*Teleology*] (Oxford, 2005).
- Judson, L., ‘Aristotelian Teleology’, *Oxford Studies in Ancient Philosophy*, 29 (2005), 341–66.
- Lennox, J. G. (trans. and comm.), *Aristotle: On the Parts of Animals I–IV* [*Parts of Animals*] (Oxford, 2001).
- *Aristotle’s Philosophy of Biology* [*Philosophy of Biology*] (Cambridge, 2001).
- ‘Nature Does Nothing in Vain’, in H.-C. Günther and A. Rengakos (eds.), *Beiträge zur antiken Philosophie: Festschrift für Wolfgang Kullmann* (Stuttgart, 1997), 199–214; repr. in J. G. Lennox, *Aristotle’s Philosophy of Biology* [*Philosophy of Biology*] (Cambridge, 2001), 205–23.
- ‘Teleology in Scientific Explanation: Commentary on Henry and McDonough’, presented at the annual meeting for the American Philosophical Association (Boston, 2010).
- Leunissen, M., ‘Crafting Natures: Aristotle on Animal Design’, in G. Dicker (ed.), *Annual Proceedings of the Center for Philosophic Exchange* (SUNY Brockport, 2012), 28–51.
- *Explanation and Teleology in Aristotle’s Science of Nature* [*Explanation and Teleology*] (Cambridge, 2010).
- and Gotthelf, A., ‘What’s Teleology Got to Do with It? A Reinterpretation of *Generation of Animals* V’ [‘GA V’], *Phronesis*, 55 (2010), 325–56; repr. in A. Gotthelf, *First Principles* (Oxford, 2012), ch. 5.
- Lloyd, G. E. R., *Aristotelian Explorations* (Cambridge, 1996).
- Sedley, D., *Creationism and its Critics in Antiquity* [*Creationism*] (Berkeley, 2007).
- ‘Is Aristotle’s Teleology Anthropocentric?’ [‘Anthropocentric’], *Phronesis*, 36 (1991), 179–96.
- ‘Teleology: Aristotelian and Platonic’ [‘Aristotelian and Platonic’], in J. G. Lennox and R. Bolton (eds.), *Being, Nature, and Life in Aristotle* (Cambridge, 2010), 5–29.
- Sharples, R. W., ‘The Purpose of the Natural World: Aristotle’s Followers and Interpreters’, in J. Rocca, *Teleology in the Ancient World* (Cambridge, 2013, forthcoming).
- Strange, S. K., ‘The Double Explanation in the *Timaeus*’, in G. Fine (ed.), *Plato 1: Metaphysics and Epistemology* (Oxford, 1999), 397–415.

- Wieland, W., 'The Problem of Teleology', in J. Barnes, M. Schofield, and R. Sorabji (eds.), *Articles on Aristotle*, i. *Science* (London, 1975), 141–60.
- Witt, C., 'Aristotle on Deformed Kinds', *Oxford Studies in Ancient Philosophy*, 43 (2012), 83–106.