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Embryological Models in Ancient Philosophy

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ABSTRACT
Historically embryogenesis has been among the most philosophically intriguing phenomena. In this paper I focus on one aspect of biological development that was particularly perplexing to the ancients: self-organisation. For many ancients, the fact that an organism determines the important features of its own development required a special model for understanding how this was possible. This was especially true for Aristotle, Alexander, and Simplicius who all looked to contemporary technology to supply that model. However, they did not all agree on what kind of device should be used. In this paper I explore the way these ancients made use of technology as a model for the developing embryo. However, my purpose here is more than just the historical interest of knowing which devices were used by whom and how each of them worked; I shall largely ignore the details of how the various devices actually worked. Instead I shall look at the use of technology from a philosophical perspective. As we shall see, the different choices of device reveal fundamental differences in the way each thinker understood the nature of biological development itself. Thus, the central aim of this paper is to examine, not who used what devices and how they worked, but *why* they used those particular devices and what they thought their functioning could tell us about the nature of embryological phenomena.

Part 1. *Introduction*

Historically embryogenesis has been among the most philosophically intriguing phenomena. Witness the fact that an embryo, left to itself, does not break down into its constituent elements but instead undergoes a series of complex transformations that build it into an organism of the same kind as its generating parents. Given this spectacular feat, it is no surprise that

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embryogenesis has long been a primary motivation for a belief in teleology. To us the phenomenon may no longer remain a source of wonder. However, imagine how it must have looked to an ancient who knew nothing of the biochemical basis of life or DNA. To appreciate the sense of wonder that embryogenesis must have instilled in him, consider the following scenario.

Imagine a paper cup lying by the side of the road. If left alone, the cup will eventually break down into its constituent elements. From the perspective of modern science where all material objects change according to their physical nature in ways that obey strict universal laws, the fact that the cup breaks down rather than, say, changes into a lamp is not very astonishing. It breaks down because it is made of certain kinds of materials whose nature is to change in that way. But now imagine that right before our eyes those same materials recombined into the form of a cup (rather than a lamp).[2] This would indeed be an amazing feat. For we should have expected those materials to remain in a pile and never (except perhaps by freak chance or human intervention) change back into a cup. Further imagine that this amazing event not only happened with remarkable constancy but that the general phenomenon was ubiquitous in the world. Everywhere you turned different pockets of matter were organising themselves into different things. Some built themselves up into chairs, others into bookshelves, and still others into increasingly more complex objects like flying machines and automobiles and large food-processing plants!

This little thought experiment gives us some idea of how embryogenesis would have looked to an ancient. It was a source of philosophical wonder and puzzlement. Of course there were some materialists who argued that all of the morphogenetic changes an embryo undergoes can ultimately be traced to the fact that it is made out of such-and-such basic materials whose own nature is to move in certain ways and undergo certain kinds of change. However, this project turned out to be largely unsuccessful (and remains so).[3] For others, most notably Aristotle, embryogenesis

[2] A better analogy would be if some materials fell off the paper cup and came into contact with materials from another cup, while the product of their interaction organised itself into a third cup like the first two.

[3] For a modern example of this project see Turing 1992. The most common materialist explanation for embryogenesis was that the complex structures at the end of the process were there all along preformed inside the embryo. Here development is seen as nothing more than the augmentation of those preformed structures. For a good his-

was a beautifully choreographed performance that could not be meaningfully understood by thinking of an embryo as being like any other physical object whose behaviour is determined solely by what it is made out of together with strict laws acting uniformly on every other object in the universe.

In this paper I shall focus on one aspect of biological development that was particularly perplexing to the ancients: self-organisation. For many ancients, the fact that an organism determines the important features of its own development required a special model for understanding how this was possible.[4] This was especially true for Aristotle, Alexander, and Simplicius (the main focus of this paper) who all looked to contemporary technology to supply that model. However, as we shall see, they did not all agree on what *kind* of device should be used. In this paper I shall explore the way these ancients made use of technology as embryological models. However, my purpose here is more than just the historical interest of knowing which devices were used by whom and how each of them worked; I shall largely ignore the details of how the various devices actually worked. Instead I shall look at the use of technology from a philosophical perspective. As we shall see, the different choices of device reveal fundamental differences in the way each thinker understood the nature of biological development itself. Thus, the central aim of this paper is to examine, not who used what devices and how they worked, but *why* they used those particular devices and what they thought their functioning could tell us about the nature of embryological phenomena.[5]

Before we begin, it will be helpful to introduce three kinds of device that will be relevant to our discussion: marionettes, mechanical puppets, and self-moving automatons. A marionette is the most familiar kind of puppet, whose limbs are moved independently of one another by a puppeteer manipulating strings attached directly to each limb. What I shall call "mechanical puppets" are devices whose motion is also generated externally; however, all of its limbs are moved by pulling a single master cord rather than by different strings attached directly to each limb. For

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torical discussion of the debate between epigenesis and preformationism (18th-19th century) see Maienschein 2000.

[4] This still remains true in modern times. For a particularly relevant example see Apter 1966.

[5] For a good historical survey of the use of technology in the ancient world see Brumbaugh 1968 and Humphrey, Oleson, and Sherwood 1998. The present paper owes a great deal to these exceptional studies.

example, as a child I would be entertained for hours by a puppet whose arms and legs flailed wildly up and down as I tugged on the string coming out of the bottom. In this case the single linear motion introduced into the system by pulling the cord gets transformed into four complex up-and-down movements as it passes through a network of internal gears.[6]

A third and final type of device I shall introduce here is the self-moving automaton. Unlike the first two devices, the motion that powers an automaton is generated internally (rather than externally by a puppeteer manipulating strings or an operator pulling a cord). What I shall call "mechanical" automatons are those whose movements are generated by a series of physical gears inside the device (like the cogs and wheels inside a modern clock) that move one another in succession once the external agent sets the mechanism going.[7] The differences between these three kinds of device (both physical and philosophical) will be developed as we proceed. This should be enough for a starting point.

Although the focus of this paper is on the use of technology as a source for embryological models, it is necessary to begin with Aristotle's *de motu animalium*. For this has traditionally been seen as the source of Aristotle's embryological analogy in *de generatione animalium* (*GA*).

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[6] By "gears" I mean any system of mutually adapted mechanical parts working together inside a device which are organised in such a way as to produce a given effect (in this example turning the simple linear motion generated by pulling the cord into the complex up-and-down motions of the puppet's limbs). In Part 3 I shall distinguish between "active" and "passive" gears. The gears in the mechanical puppet are passive in that they do not initiate motion themselves but are moved by an external agent (e.g. an operator pulling a cord). An ancient example of a mechanical puppet is supplied by Herodotus, who describes an Egyptian puppet a cubit tall with an oversized phallus; the phallus was made to move up and down when the person pulled the string coming out of its back. This is discussed by Preus 1981, 85. The θαύματα from Plato's *Republic* 514B also seem to be mechanical puppets of this same sort (see Farquharson's translation in Ross 1912 ad loc *de motu* 701b1-2).

[7] Cf. Balme 1972, 157. Berryman 2002 (esp. 245) provides an excellent description of what I am calling a "mechanical" automaton. I am taking the "mechanical" automaton as one kind of self-moving automaton. There may be other (non-mechanical) kinds, for example, ones that owe their movements to the execution of an internal programme (in the modern sense) rather than a network of physical gears. However, the majority of our discussion of automatons will focus on the mechanical kind (though see below).

The de motu *analogy*

Aristotle thinks the mechanical automaton provides an ideal model for understanding the biomechanics of animal motion. We are introduced to this analogy in a famous passage from *de motu* 7:

T1. The movements of animals may be compared with the automatons (τὰ αὐτόματα) which are set in motion when a small change occurs releasing the cables causing the pegs to strike against one another[8] . . . . Animals have organs of this sort, namely the <material> nature of the tendons and the bones: the bones correspond to the wooden pegs and iron <axles>[9] inside the automatons, while the tendons correspond to the cables, the release and slackening of which causes movement. (701b1-10)

We need not be overly concerned with the details of the mechanism Aristotle has in mind here. For the sake of convenience we can imagine an automaton whose internal gears consist of a series of toothed-axles in contact with one another (the teeth being the wooden pegs?) with weighted cables wound around the first axle. When the cables are released, the weights drop causing the first axle to spin. The motion is then transmitted through the remaining axles as the pegs from one strike against those of another in a sequence until all the axles have been set in motion. The important point for our purposes is that the movements of the automaton itself are generated *internally* by the motion passing through its gears: one axle moves the next in succession and in virtue of this moves the automaton along. The idea, then, is that just as releasing the cables causes locomotion in the automaton, so too the perception (image, thought) of an object of desire causes locomotion in the animal (cf. 701b13 ff., 702a18-21).

Aristotle highlights two points of analogy in T1. The first is between the physiological changes leading from perception to bodily movement and the chain reaction set off inside the automaton: both involve a chain of causes and effects (i.e. a causal sequence). In the latter case, releasing the cables causes motion in the first axle which in turn causes motion in the next axle and so forth causing the automaton's limbs to move.

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[8] Reading λυομένων τῶν στρεβῶν, καὶ κρουόντων ἄλληλα τῶν ξύλων following Nussbaum (1976, 150).

[9] Nussbaum (1976, 150) rightly rejects Forster's (1993, 462 *n.* c) suggestion that the "iron" Aristotle mentions in our passage refers to parts of the toy cart (referred to in the elided text). The iron, Nussbaum suggests, most likely refers to axles inside the automaton (as described by Hero).

Likewise in the animal, the perception of an object of desire causes heating and cooling in the region around its heart causing it to expand and contract, which pulls on the tendons attached directly to the limbs, which in turn causes its limbs to move accordingly.

What makes this causal sequence possible, Aristotle thinks, is the fact that animals, like mechanical automatons, are equipped with internal 'gears'. This is the second point of analogy highlighted in T1: "Animals have organs of this sort, namely the <material> nature of the tendons and the bones: the bones correspond to the wooden pegs and iron <axles> in the automatons, while the tendons correspond to the cables, the release and slackening of which causes movement." This adds a further dimension to the analogy. For what explains the fact that a given input *A* leads to a particular remote effect *E* is the organisation of the mechanism inside the device, i.e. the arrangement of its internal gears. It is *because* the animal's heart is connected to the tendons which are in turn connected to the limbs that the perception of an object of desire causes bodily movement rather than some other remote effect.[10]

With this analogy in mind, let us turn our attention to the embryological domain. Before doing so, I should first say a word about the order of our discussion. I shall begin with Alexander followed by Simplicius and postpone the discussion of Aristotle's embryological model until the final section. The main reason for beginning with Alexander is that, as we shall see, the conventional reading of Aristotle's use of automatons in *GA* (which I shall eventually challenge) goes all the way back to Alexander. Thus, if we began with Aristotle, we would first have to sketch out the traditional interpretation so that by the time we got to Alexander most of the discussion would be redundant. However, I believe there is tremendous philosophical value in exploring Alexander's interpretation in its own right for what it reveals about his particular insights into the concept of "nature" and how it operates in embryogenesis. This will then have the added advantage of supplying us with the traditional interpretation of Aristotle's use of automatons in *GA*.[11]

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[10] Cf. Nussbaum 1976, 146-7. For a contrasting view see Berryman 2003, 359. Berryman argues that this aspect of animal locomotion is explained by a special kind of *pneuma* and not by any internal configuration of parts (and so exhibits a disanalogy with automatons). I think Berryman assigns too great a role to *pneuma* in Aristotle's account of motion (*de motu* 10).

[11] The reason for dealing with Simplicius after Alexander will be obvious: Simplicius is reacting to Alexander.

Part 2. *Alexander*

In *Metaphysics* Zeta 8 Aristotle argues that biological organisms have the ability to generate copies of themselves without the need for Platonic Forms as models.[12] Alexander was therefore quite worried by the fact that, at *Metaphysics* 1013a26 and again at *Physics* 194b26, Aristotle himself refers to the form as a model (παράδειγμα). Alexander insists that what Aristotle is referring to here is not a separately existing Platonic Form but the form instantiated in the matter, i.e. the offspring's actualised form. That form acts as a model, Alexander says, not in the sense that nature produces what it produces while looking to it (as at, e.g., *Timaeus* 23A ff.), but rather in the sense of being a target (σκοπός), i.e. the goal of the process:

> Alexander says: 'Things that produce naturally do not first conceive of (νοήσαντα) what they are producing and then produce it in such a way that one could say the thought (τὸ νόημα) is a model of the things that come to be according to it, as it is in the case of the arts; rather, it is the form that embraces the matter[13] that he [Aristotle] calls a model because nature produces everything it produces by aiming at (ἐφιεμένην) this. This [sc. the fact that nature produces what it produces by aiming at the actualised form] is clear from the fact that when it has been generated nature ceases producing, because the form is a sort of boundary[14] and is, as it were, set up as a target (σκοποῦ προκειμένου) towards which nature stretches (τέταται), and for this reason it is called a model.' (Alexander *ap.* Simplicius *in Phys.* 310,25-31; cf. *in Metaph.* 349,7-17)

In this passage Alexander points to the fact that development stops when it reaches the species-form as evidence that that form is the goal or target of the process.[15] The idea is that nature no longer continues to act once the thing for the sake of which it was acting has been brought to completion, since at this point it has reached its goal.[16]

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[12] *Metaphysics* Z8, 1033b26-1034a5. I discuss this argument in Henry 2003.

[13] Literally, the form that comes to be around the matter (περὶ τῇ ὕλῃ εἶδος), i.e. the actualised form. Alexander elsewhere calls this the "enmattered (ἔνυλος) form" (*in Metaph.* 360,5).

[14] ὡρισμένου τινός. Compare *Metaphysics* Δ17 where Aristotle speaks of the form of each thing as being a limit (πέρας), which he opposes to the beginning or starting-point (ἀρχή) of development. Alexander picks up on this idea at *in Metaph.* 413,31-3: "He [Aristotle] says that limit also means 'the end (τέλος) of each thing', that for the sake of which, for it is this 'towards which movement and action are directed', since that for the sake of which movement and action <began> *and at which they ceased* is a limit."

[15] Cf. *Parts of Animals* 1.1, 641b24-7.

[16] The Neoplatonists also took the fact that development stops once it reaches the

This phenomenon is known in modern contexts as homeorhesis. Homeorhesis, and its cousin homeostasis, are often cited by modern biologists as evidence for the goal-directed character of certain biological processes, most notably embryonic development.[17] In homeostasis the system maintains a stable state (e.g. the function of a thermostat is to maintain a constant room temperature). In homeorhesis, on the other hand, the system does not maintain a single state but changes its state while maintaining a constant trajectory towards a preferred state of rest. Development is a homeorhetic process in this sense. A developing embryo does not maintain the same shape and size over time; rather, it changes its shape and size while maintaining a constant growth pattern or developmental trajectory towards its adult form.[18] As we shall see, Alexander identifies "nature" as the mechanism[19] inside the developing embryo that is responsible for this phenomenon.

The remarkable ability of a developing embryo to maintain, by itself, a constant trajectory towards its adult form has led many philosophers and biologists (both ancient and modern alike) to see the process of development as being internally directed towards that form as its goal.[20] As Calow puts it, it is as if the developing embryo knows exactly what it wants to be and even in the face of violent and unpredictable disturbances still manages to achieve its ambition.[21] Historically at least, this same phenomenon has also led many to posit an intelligent agent behind the scenes directing the process and calculating each step in advance with a view to the end.[22] Following Aristotle, Alexander rejected this idea and insisted that genuinely goal-directed behaviour is not limited to the actions of intelligent beings.[23] In organic development, while the species-form is the tar-

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species-form as evidence that the process is directed towards that form as its goal. See Philoponus *in Phys.* 196,18-26 and Simplicius *in Phys.* 375,15-24.

[17] See, e.g., Calow 1967; Hull 1974.

[18] Calow 1967, 11.

[19] I am using "mechanism" here in the broad sense to refer to the means by which a particular effect is produced or (more generally) something that performs a specialised function, as when we say the heart is a mechanism for pumping blood.

[20] Cf. Fox Keller 2000, 252. For the Ancients see Aristotle *Physics* 2.8, 199b13-18; *Parts of Animals* 1.1, 641b24-27. For a modern perspective on goal-direction in biological processes see Apter 1966; Hull 1974, Chp. 4; Mayr 1992. A contemporary attack on natural teleology can be found in Nissen 1997.

[21] Calow 1976, 9. See also Maienschein 2000.

[22] Alexander's rival, Galen, was among those who advocated this position (see esp. *On the Construction of the Embryo*).

[23] Compare *Physics* 2.8, 199b26-33.

get of the process, it is not something that first exists in the mind of the producer as an idea of the finished product:

> 'But the goal or model,' Alexander says, 'does not exist in the same way in the case of everything that produces for the sake of something. In the things that act according to deliberate choice (προαίρεσις), art, or reason the goal for the sake of which the other things come to be must have first been conceived (νοηθέν) by the producer and set up <in his mind> (ἐκκεῖσθαι) as a target (i.e. model) of what will be, but in the things that come to be by nature <the goal> does not exist in this same way. For nature does not operate according to deliberate choice or any rational principle in it, for nature,' he says, 'is a non-rational power (ἄλογος δυνάμις).' (Alexander *ap.* Simplicius *in Phys.* 310,31-311,1)

The continuation of this text (translated below) will be the primary focus of our discussion. However, we first need to say a bit more about Alexander's idea here.

For Alexander the species-form is the target *towards which* the process of development advances (cf. 311,29-30); "nature" is the principle inside the developing embryo that is responsible for the fact that the process hits this target by ensuring the changes follow one another in the proper order. However, it does not do this by calculating the steps to the goal beforehand. For nature is a non-rational power:

> For it is not by reflecting (ἐννοοῦσα) that nature produces what it does (for it is a non-rational power), but it is responsible for the fact that <development> takes place in an orderly progression of changes[24] so that a first change is followed in an orderly sequence by a second change, though not in virtue of any calculation (κατὰ λογισμόν), and that this is followed in turn by a third, until the changes have advanced (προέλθωσιν) to the end for the sake of which they came to be. (Alexander *in Metaph.* 103,37-104,1)

Let the sequence $A \rightarrow G$ represent the developmental trajectory for a given species of organism, where G marks the end of the process initiated by the generator and A through F the steps leading up to that end.[25] The goal-state G is reached when an organism of the same species as the parent exists. What Alexander is saying is that "nature" is the principle inside

[24] For the most part I shall translate κίνησις as "change" in the embryological context (since it conveys a much broader and more organic sense) and "motion" when referring to the causal sequence inside a mechanical automaton (since it would be awkward to speak of one axle "changing" another).

[25] There is a question as to what Alexander takes *A B C* etc. to refer to: stages of development or parts of a whole? This will be addressed in Part 3. For now I shall refer to these simply as *states* of the developing embryo (where *G* is the final state, i.e. the completed form), which is intended to be neutral on this question.

the embryo that is responsible for the fact that development reaches this target by co-ordinating the intermediate steps in the process so that a first change to *A* is followed in an orderly fashion by a second change to *B* which is in turn followed by a third change to *C*, and so forth.[26] However, Alexander insists that while development is a *rational sequence*, insofar as the transition from one state to the next takes place according to a definite teleological order, nature is not a *rational agent*.

Alexander's point here turns on the distinction he draws between two senses of "rational". This distinction is made explicit by Simplicius at *in Phys.* 313,27-34:

> But how can he [Alexander] call nature a *non-rational* power even though it produces for the sake of something and progresses in an orderly manner according to determinate numbers and measures? The answer is that 'the productive λόγος' is two-fold. The one produces with a capacity based on knowledge (γνωστικόν), which the interpreter [Alexander] believes is rationality alone; the other produces without knowledge and self-reflection, but still in an orderly and determinate manner and directing the process (προηγουμένου) for the sake of some end. And just as that which produces without knowledge is non-rational (ἄλογος) in relation to the rational one that produces with knowledge, so too that which produces in a random and disorderly manner is non-rational in relation to the one that acts in an orderly and determinate way and for the sake of something. Therefore, what comes to be by nature does so according to a λόγος of this latter sort, so it also comes to be according to a model, not as something which acts with foreknowledge (γνωστὸν προκείμενον), but because the producer makes the product like itself by being <itself>, not by choosing, just as the signet-ring makes the impression <in the wax>.

Simplicius agrees with Alexander that nature (the principle that regulates the process of development) is a *non-rational* agent, in the sense that it produces the end without knowledge and self-reflection, even though it can be said to follow a *rational* sequence, in the sense that the steps follow upon one another in the order necessary for achieving that end (cf. Philoponus *in Phys.* 244,14-23). However, as we shall see, Simplicius goes on to say that this is only half the story. For the plan that nature follows in producing the adult form is itself the product of an intelligent agent

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[26] As we shall see, Alexander thinks the nature in the embryo co-ordinates the steps to the goal *in real-time*, i.e. as the process unfolds (the meaning of this hangs on the analysis of "nature" below). This is opposed to a theory like that of Simplicius, who speaks of the nature in the seed as "anticipating" (προλαμβάνει; 313,22: προείληπται) the λόγος of the whole ordered process. Here the organism develops according to that λόγος which pre-exists in the seed. For more on this see Part 3 below.

who did calculate the intermediate steps in relation to that end while looking to a Form as its model.

We can summarise Alexander's argument thus far as involving two negative claims about the activity of nature in organic development. First, Alexander argues that an embryo's nature does not build the organism by looking to a Form as its model; it does not first conceive of what the product should be like and then generate the offspring according to its conception. Rather, the form is a model only in the sense of being a target or goal *towards which* the process advances.[27] Second, and more importantly, nature is responsible for the fact that development maintains a constant trajectory towards that form by ensuring the changes follow one another in the proper sequence. However, it is not through any principle of reasoning or foresight that nature is able to do this, for it is a non-rational power (ἄλογος δυνάμις). For Alexander, a developing embryo is a *naturally* goal-directed system where the goal is not an independent idea but simply the end point of its developmental trajectory, the state *towards which* the process advances.[28]

Alexander's embryological model

The devices Alexander uses to illustrate his account of biological development are mechanical automatons – the same devices Aristotle had used in *de motu* as a model for animal locomotion.[29] We find Alexander deploying this model in his commentary on Aristotle's *Physics*, in a passage which Simplicius has preserved for us. It will be useful to translate this rather difficult bit of text so that we have it in front of us as we proceed:

> But when the initial principle has been implanted in the matter which is receptive of both the principle and the things that are to come into being by its agency

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[27] Recall that this form is the form instantiated in the matter, the end-state in which the process terminates.

[28] Although Simplicius agreed with Alexander that when Aristotle calls the form a model or παράδειγμα, he does not mean it is some self-subsisting Platonic Form, he denied that by calling it a "model" Aristotle means it is the goal *towards which* development advances. To call the thing towards which something moves a model, Simplicius contends, is to lose sight of what it is to be a model (312,1-18). His point here is that there is an important conceptual difference between a target (σκοπός) and a model (παράδειγμα) that Alexander glosses over.

[29] Although in the text below the Greek reads τὰ νευροσπαστούμενα (e.g. 311,8), which generally refers to devices moved by pulling strings, there is no question that Alexander has mechanical automatons in mind. As such "automaton" appears in the translation below, as "puppet" would distort Alexander's philosophical point.

> and from it, this thing (the principle that was implanted first) produces of itself that which is itself productive of something determinate, while what comes to be from it in turn produces another thing; for each of them is itself both productive of, and capable of setting in motion, the thing which comes after it (if nothing prevents it). And this continues up to a specific end, i.e. the form of the natural thing whose principle was first implanted in the matter, just as in the case of automatons: once the operator supplies the beginning of motion to the first thing, this thing itself becomes capable of setting in motion the one after it, and this in turn becomes capable of setting in motion the next thing in the series, and so forth until the motion has run through all of them (unless something prevents it), the one before moving the one after of itself, not in accordance with any reason or deliberate choice in the things themselves. In the same way, when the nature and potential (δυνάμις) implanted together in the sperm come to be in the appropriate matter, being capable of changing it, it changes it in the precise way in which the one [sc. the sperm] is naturally suited to produce change and the other [sc. the matter] to be changed. And the potential which is engendered from the first change in turn produces another change and another potential, and this continues until it produces that which is like that from which the sperm comes, identical with it either in species or in genus (as in the case of those born from different animals, e.g. mules; for they are the same in genus with those that produced them). And this relay (διαδοχή) occurs according to certain numbers and a certain order until the offspring is complete with respect to its form (if nothing prevents it). . . . Therefore, the form is a model, because nature has tended towards this (νένευκεν), not by deliberate choice, but rather as the automatons do. (Alexander *ap.* Simplicius *in Phys.* 310,36-311,19; 29-30)

As I have said, the device Alexander uses for an embryological model in this passage is the very same device Aristotle used in *de motu* to illustrate animal motion (the mechanical automaton). Crucially underlying Alexander's analogy is the idea that, just like the chain of events set off by the operator, the process leading from embryo to adult is a causal sequence where each member in the series is "itself both productive of, and capable of setting in motion, the thing which comes after it". This is set out in the first part of the text: the father's sperm generates a first state *A*, "which is itself productive of something determinate" *B*, while "what comes to be from it [viz. *B*] in turn produces another thing" *C*. This chain of causes and effects continues in succession until what exists is an organism with the same shape and form as its parents. In this way Alexander's embryological use of the mechanical automaton echoes the *de motu* analogy.[30]

[30] Recall that being a causal sequence (where the action of the first mover is taken up by something else and is passed on from one member of the series to the next in succession) is what Aristotle thinks warrants the application of the automaton analogy to animal locomotion in the first place: the process leading from the perception of an

Alexander's analogy needs to be made more explicit. What Alexander wants to argue is that a developing embryo maintains a certain teleological order in the process of its development, not in virtue of any reason or choice, but simply because of its nature – which was just said to be a *non-rational* power (310,36-311,1). Alexander brings in the mechanical automaton here because it offers an example of something that is able to execute an orderly sequence of movements and is obviously devoid of reason and deliberate choice.[31]

However, this is not all that is going on in our focal text. For Alexander introduces the analogy with automatons on the basis of a statement about the way nature operates in development (ἡ φύσις ἐργάζεται). What does the analogy with mechanical automatons tell us about the activity of nature? To answer this, consider the following passage from ps.-Aristotle *Mechanics*:

> Because a circle moves with two contrary forms of motion at the same time, and because one extremity of the diameter, *A*, moves forwards [clockwise] and the other, *B*, moves backwards [counter-clockwise], some people contrive so that as a result of a single movement [sc. the movement of *A*] a number of circles move simultaneously in contrary directions like the wheels of brass and iron which they make and dedicate in the temples. . . . The same thing will happen in the case of a larger number of circles [*ABCD*], only one of them [*A*] being set in motion. *Mechanists, seizing on this inherent peculiarity of the circle, and hiding the source <of motion>, construct an instrument so as to exhibit the amazing character of the device, while concealing the cause of its <movements>.* (848a20-37, Forster transl. with modifications)

This passage highlights two features of a mechanical automaton that could serve as the object of analogy: the *external* motion of the automaton itself (the movements of its limbs) and the *internal* motion of its mechanical gears. In a mechanical automaton, the internal movement is literally a causal sequence passing through a series of axles (or brass wheels) moving one another in succession. This motion, which the mechanist seeks

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object of desire to the appropriate bodily response is a case of one thing moving another in succession like the movements of mechanical automatons. Alexander thinks development is a sequence of this same sort. For Aristotle's own position on the sequence of development, and thus the appropriateness of the mechanical automaton as an embryological model, see Part 4 below.

[31] The fact that an automaton is designed and constructed by an intelligent agent will not affect its usefulness as a model for a developing embryo. For the relevant point of analogy is the actual functioning of the (already constructed) mechanism not its causal origin.

to conceal from us, is the hidden source of the automaton's external movements.[32]

I want to suggest that Alexander's analogy is primarily targeting the internal (hidden) motion of the automaton's gears and only secondarily the external (observable) motion of the automaton itself. More specifically, he is drawing an analogy between *the nature* inside the developing embryo and *the gears* inside the mechanical automaton. The gears of the automaton are the hidden source of its amazing ability to execute a complex sequence of movements without reason or deliberate choice. Likewise, Alexander wants to say, the nature inside the developing embryo is the hidden source of its amazing ability to undergo a complex pattern of morphogenetic changes of its own accord without having to calculate each movement or change in advance with a view to the end. What Alexander presents us with is thus a two-tiered analogy (with the primary focus on the second tier): the developing embryo = the moving automaton; the nature inside the embryo = the network of gears inside the automaton that causes its motion.

At first glance it appears that Alexander has taken the analogy with a mechanical automaton too far. For there seems to be a glaring disanalogy between the nature of the embryo and the network of gears inside the automaton. As we have seen, Aristotle thinks the mechanical automaton provides an ideal model for illustrating the movements of animals (T1). One of the reasons is that he thinks animals are equipped with internal 'gears':

> Animals have organs of this sort, namely the <material> nature of the tendons and the bones: the bones correspond to the wooden pegs and iron <axles> inside the automatons, while the tendons correspond to the cables, the release and slackening of which causes movement.

The biomechanical nature of animal motion (the fact that animals are equipped with internal parts that function like gears) is thus an essential feature of the *de motu*'s application of the automaton analogy. However, the analogy seems to break down when we try to apply this feature to the development of an embryo. Given that an undifferentiated embryo does

[32] Aristotle in the *GA* (see T2 in Part 4 below) explicitly refers to "the internal motion" (ἡ ἐνοῦσα κίνησις) as a cause of the automaton's (external) motion. A modern example of this distinction is provided by a mechanical clock, which also works on the same principle as the mechanical automaton. The "external" motion is the motion of the hands around the face, which we observe; the "internal" motion which causes those hands to move is the movement of the clogs and wheels inside the device.

not yet have any actual structures like the bones and sinews inside a locomotive animal, it is difficult to imagine what in the embryo would correspond to the cables and axles inside the automaton. The way Alexander gets around this problem is quite ingenious.

As we have seen, Alexander thinks the development of an embryo towards its adult form is caused by the activity of its nature in the way the movements of an automaton are caused by the motion of its internal gears. Clearly Alexander does not think nature is literally a network of mechanical gears hidden inside the embryo whose parts move one another in succession. The analogy Alexander has in mind is much more subtle than this. Just as one axle moves another and in virtue of this moves the automaton along, so too one embryonic state *produces* another and in virtue of this moves the process of development along towards the final state (the complete form). What makes this analogy work is the idea that each state that comes to be in the course of development has within it a principle (i.e. a nature), which is the source of a change leading to another determinate state. In this way the transition from one state to the next is caused by the nature of the antecedent state: $A \rightarrow B$ is caused by the nature of *A,* $B \rightarrow C$ by the nature of *B*, and so forth. Instead of mechanical gears, then, what we have are individual states of development linked together in a causal chain by their specific natures.[33]

There is one final point of analogy to highlight before turning to Simplicius. Alexander argues that nature (taken as a generalisation over the natures of each state) is a "non-rational" power in the sense that it acts without deliberate choice. The analogy with the gears of the automaton again helps to illustrate this idea. When the operator sets the first axle *A* in motion, it immediately becomes capable of setting the next one *B* in motion (311,8-9). The power *A* has to move *B* is a non-rational power. What this

[33] One implication of this view is that the "nature" that ensures the various states of development follow one another in the proper sequence (cf. *in Metaph*. 103,37-104,1 translated above) is reducible to the sum of natures of individual states, each of which is the source of a change leading to the state that comes after it. As we shall see, this is the view Simplicius ascribes to Alexander (the potential to produce the organism as a whole is just the sum of potentials for producing the different parts of the whole). An alternative reading (suggested by an anonymous referee) is that the "nature" of the developing organism is something over-and-above the sum of state-natures. One problem with ascribing this view to Alexander, however, is that it finds no analogue in the case of the mechanical automaton (there is no single principle over-and-above the power each axle has to move the one next to it). As such, the analogy with automatons would leave the activity of "nature" unexplained.

means is that when *A* moves *B* it does not do so according to any principle of reason or choice within itself but strictly of necessity. Aristotle's discussion of rational and non-rational powers in *Metaphysics* Θ5 is useful for understanding this point.

With rational powers, Aristotle says, each is capable of bringing about contrary effects, for example, the art of medicine is a potential to produce both health and disease (cf. *Metaph.* Θ2). However, since it is impossible to induce both of these in the patient simultaneously (being contrary states), there must be something else present besides the potential itself that "has authority over" action, namely desire and choice:

> For whichever of two effects the animal desires authoritatively (κυρίως) it will do, when it is in the appropriate circumstances and meets with the patient. Therefore, everything which has a rational power, when it desires that for which it has the power and is in the circumstances in which it is capable of exercising that power, must do this. (1048a12-15)

With non-rational powers, on the other hand, each potential is productive of a single effect only (μία ἑνὸς ποιήσει). As such, there is no need for desire and choice to govern action. Here the occurrence of the right conditions (contact with a suitable patient) *necessitates* the activation of that potential. Once agent and patient come into contact immediately the one *must* act and the other *must* suffer action (1048a5-7).[34]

The parts of the automaton's network of gears are like this: each axle in the series only has the power to initiate motion in its immediate neighbour. Because each axle is only productive of this single effect, it does not have to *want* to move the one next to it and then *choose* to move it; rather, each axle generates motion in the next *of necessity* without desire and choice.

By calling nature a "non-rational" power Alexander is saying that each state that comes into being in the course of development is naturally suited to produce *only* the state that comes after it without being able to produce another, contrary state. As such, once a given state has been brought into being (by the one before it), it immediately generates the next state according to its specific nature, not by reason or choice, but *of necessity*. In this way the responsibility of generating the organism as a whole is transmitted from one state to the next in a causal "relay" (διαδοχή: 311,18): "the potential which is engendered from the first change *in turn*

[34] Cf. Sorabji 1980, 52-3. Fire's power to melt ice is a good example of a "non-rational" δυνάμις.

produces another change and another potential, and this continues until it produces that which is like that from which the sperm comes". For Alexander, then, "nature's" power to generate a complex series of changes – something Galen argued must require "an enormous degree of skill and intelligence" (*On the Construction of the Embryo*, 701-2) – can be analysed into a causal sequence of non-rational powers, namely, the power each state has to generate the one that comes after in virtue of its particular nature.[35]

By assimilating the development of an embryo to the movements of automatons, Alexander was able to solve the problem associated with the goal-directed character of development. The problem, recall, is understanding how nature can be responsible for the fact that development hits its target (the species-form) without being a deliberate agent who calculates each step in advance while looking to a form as a model.[36] As we have seen, Alexander solves this problem by analysing the mechanism of nature into a succession of non-rational powers so that the goal-state is reached automatically through a causal sequence triggered by the action of the father's sperm.[37] On this "relay" model of development, each thing that comes into being is "naturally suited" (πέφυκε) to produce the thing that comes after it, not according to reason or choice, but simply in virtue of its nature (which is a non-rational δυνάμις). The automaton analogy was important here because it provided Alexander with a well-understood paradigm system from which to extrapolate this conclusion. It offered an example of how something devoid of reason can still be said to follow a "rational" sequence in the sense of proceeding in an orderly and determinate manner for the sake of some end (cf. *in Phys.* 313,27-34, translated above).

Finally, we can note that the mechanical nature of the changes that make up the developmental sequence (which is implied by this model) will have no bearing on Alexander's evaluation of that sequence as being goal-directed, since the teleological nature of development is given by its

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[35] Compare Cummins 1975, 764-5.

[36] Cf. Simplicius *in Phys.* 314,1-3: ἀλλὰ πῶς ἄνευ γνώσεως τοῦ ποιοῦντος ἔστι τάξις καὶ ὡρισμένον τέλος ἐν τῇ ποιήσει.

[37] We can add here that the starting change in the sequence, which is caused by the external agent (the sperm), is itself the result of the activation of a non-rational δυνάμις. The potential in the father's sperm is *only* productive of that first state *A* without being productive of another, contrary state *A′*. As such, the sperm generates that first state *of necessity* upon contact with the mother's egg.

homeorhetic character. For Alexander, the fact that the process stops once the organism has attained its adult form clearly shows that that form was the goal of that process. That this goal was reached through an automatic sequence of mechanical transformations is irrelevant.[38]

Part 3. *Simplicius*

Simplicius agreed with Alexander that nature is (in some sense) responsible for the fact that development follows an orderly progression of movements or changes without looking to the form as a model or going through a process of reasoning (e.g. *in Phys.* 313,27-34). However, he rejected the analogy with automatons and its corresponding image of a purely mechanical embryo.[39] Simplicius raises a number of objections against Alexander, though I shall only focus on two. In order to appreciate them, however, we first need to say a word about the way Simplicius reads Alexander.

Both of the objections we will look at target Alexander's idea that the process of development is composed of a series of states linked together in a causal chain by their particular natures. On this model, the responsibility of generating the organism as a whole is transmitted from one state to the next in a "relay" where the earlier states *produce* the later ones according to their particular natures. But what does Alexander take the links in this causal chain to be? (Up to now I have been using "state" as a neutral term.)

On one reading Alexander is referring to a single entity at different stages of development. For example, a human embryo passes through three distinct stages: zygote, blastula, and gastrula. These do not refer to three distinct entities; rather, they are one and the same entity at different points in its ontogenetic history. On this first reading, Alexander would be saying that the transition from one stage to the next is caused by the nature of the entity at the antecedent stage. The nature in the zygote is the source of a change whose activation moves development into the blastula stage by initiating a process of meiotic cell division. The nature in the blastula ("the potential engendered from the first change": 311,14) *in*

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[38] Bob Sharples has pointed out to me (personal communication) that mechanical processes and goal-directed processes are not antithetical from the Peripatetic point of view in general. See also von Staden 1997.

[39] By "mechanical embryo" I mean one whose development is modelled on the movements of a mechanical automaton which are generated by physical gears.

turn generates another change which causes development to enter the next stage by initiating a process of gastrulation. In this way the nature of the entity at each successive stage causes the transition to the next stage until what exists is a fully formed organism.

Alternatively, Alexander could be referring, not to a single whole passing through different stages of development, but rather to different *parts* of the whole producing one another in succession.[40] This is how Simplicius reads Alexander: "the grain produces the shoot, and the shoot produces the stalk, and the stalk produces the ear" (312,24-5).

I shall assume Simplicius' reading is correct.[41] What Alexander is saying, then, is that an organism comes into being part-by-part like putting together a jigsaw puzzle. On this model of development, the whole does not exist until the end of the process when the last part has been generated (by the penultimate part) and the offspring has its complete form. As we shall see, in contrast to this Simplicius held that even though the substance coming to be undergoes alteration during the course of its development, it still "maintains a thread of unity" (ἕνα εἰρμὸν ἀποσῴζει) throughout the process (313,17-19). In other words, for Simplicius, although development involves the gradual transformation of an embryo into an adult, the substance exists *as a whole* (i.e. retains its original unity) at every point along the way.

Simplicius raises two objections against Alexander that are worth highlighting. First, Simplicius argues that Alexander will not be able to say what the cause of the whole is (312,27-8).[42] On Alexander's model, the grain generates the shoot, the shoot generates the stalk, which in turn generates the ear. But what generates *the corn* (the whole)? Simplicius' complaint here is that Alexander only tells us about the development of the component parts of an organism, not the organism itself. And yet, since

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[40] This was a common view in antiquity. See, e.g., Aristotle *GA* 734a25-33 (translated below), Galen *On the Construction of the Embryo*.

[41] My reading of Simplicius itself may be controversial. Fleet takes Simplicius' example of grain, shoot, stalk, and ear to refer to the corn (the whole) at different stages of development rather than to parts of the corn producing one another in succession (Fleet 1997, 174 *n.* 198; cf. 173 *n.* 189). Whichever of these readings is correct, however, the target of Simplicius' objection is clear: Alexander's idea that each thing that comes into being produces the thing that comes after it so that the responsibility of generating the offspring as a whole is transferred from one thing to the next in a causal relay. Whether these 'things' refer to a single entity in different stages of development or to different parts of an emerging whole is ultimately subsidiary to this.

[42] This same problem has survived into modern times (see, e.g., Apter 1966, 32-3).

the form of the organism is one (i.e. a unity), there must be one cause for the whole rather than several causes for each of the individual parts.[43]

The second objection is connected to this. At 313,19-22 Simplicius argues that Alexander's account of the process of development is too piecemeal to capture Aristotle's idea that natural generation involves being moved *continuously* from a principle inside the developing thing itself. (This is important for understanding Simplicius' choice of technological model.) Simplicius' point is this. For Aristotle, motion or change is defined in terms of the activation of a potential for that change (*Physics* 3.1).[44] On Alexander's model the activation of the potential in the grain initiates a change that terminates in the shoot; the potential engendered in the shoot from this first change becomes the source of another change terminating in the stalk (311,12-16). The process continues in this way until all the parts of the corn have been generated. In this case, however, the development of *the corn* will not be one continuous change but a series of discrete (albeit successive) changes. In other words, the coming-to-be of the corn is not *one* change (nor is it the coming-to-be of *one* thing), since it is not the actualisation of *one* potential but the sum of actualisations of many distinct potentials.

Both of Simplicius' objections can be seen as part of a more general complaint against Alexander's idea that the nature of one part is a source and cause of generation for another part. For Simplicius, in order to explain organic development, we must have recourse to a *single* nature, which is a potential for the formation of a unified whole:

> In general, if the nature of each thing, being a source and cause of change, is productive of the subject underlying itself (τοῦ ἑαυτῇ ὑποκειμένου) and not of something else, then it is clear that while the nature of the seed will produce the seed, *the nature of the human being* will produce the human being. (Simplicius *in Phys.* 313,1-4)

Since nature is a copying mechanism (cf. 313,9-19), the nature *of* the seed would be a potential to reproduce another seed, not another human being. Consequently, the nature *in* the seed must be the nature *of* a human being, since that is the substance that comes to be from it.

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[43] ἔπειτα τί τὸ τοῦ ὅλου αἴτιον, οὐκ ἔχομεν λέγειν. ἑνὸς δὲ ὄντος τοῦ εἴδους ἔδει καὶ ἕν αἴτιον εἶναι πρὸ τῶν κατὰ μέρος (Simplicius *in Phys.* 312,27-8).

[44] Simplicius' objection here will also follow from the fact that Aristotelian changes are identified by their actualities. I am grateful to an anonymous referee for pointing this out.

Simplicius thinks the concept of a potential for the whole effectively avoids the problems associated with Alexander's relay model in a way that captures Aristotle's own account of natural generation. The nature of the human being (which is the nature *in* the seed) is productive of another actual human being. What Simplicius wants to say is that this nature is a single potential for the formation of a unified whole and not, as Alexander holds, an array of distinct potentials for the formation of individual parts (313,27-8). Not only would this tell us what the cause of the whole is, the concept of nature as a potential for the whole allows us to characterise development as *one continuous* change (the coming-to-be of *one* thing) rather than something piecemeal like a succession of genetic potentials where the potential engendered from one change in turn produces another change and another potential (311,14-16). On Simplicius' reading of Aristotle, each thing that comes into being in the course of development does so as part of the actualisation of a single potential – e.g. blade, shoot, stalk, and ear are all stages in the actualisation of a potential for *corn* (375,19-22).[45]

Simplicius' embryological model

According to Simplicius, "nature" is the propensity (ἐπιτηδειότητα) of the matter to undergo the appropriate motion or change, when it changes from one form to another (289,12-14).[46] The idea (applied to development) is that when the embryo develops into its adult form, it is the nature in the embryo that determines the pattern of changes it undergoes.[47] However, Simplicius denies that nature is an efficient cause; the function of causing motion is the exclusive province of soul:

> For Aristotle does not speak of nature as a source of movement for bodies in the way both he and Plato speak of the soul; for while the soul is capable of moving bodies (according to both), nature is a source of movement, not in respect of causing motion but in respect of being moved (κατὰ τὸ κινεῖσθαι), and of rest,

[45] A similar idea has been attributed to Aristotle more recently by Gotthelf 1987.

[46] Simplicius elsewhere refers to nature as "a propensity for being moved and regulated" (287,14), "the principle of change in the sense of being changed, not causing change" (287,25-6), "something like potentiality and the propensity to be moved" (288,10).

[47] The connection to the idea of nature as a single potential for the formation of a unified whole is the fact that Simplicius identifies the nature in the seed with "the λόγος of the whole ordered process"; the embryo develops according to this λόγος. For more on this see below.

> not in respect of causing rest but in respect of being halted (κατὰ τὸ ἠρεμίζεσθαι). That is why natural things are not said to be moved by their own agency.[48] (Simplicius *in Phys.* 287,7-12)

Since nature is a power *to be moved* in a characteristic way, not a power to cause motion, a developing embryo will not be moved by its own agency. As such, there must be something else present to supply the motion. According to Simplicius, this motion is introduced into the system from outside by the external agent (the father), which is then given teleological direction by the nature pre-existing in the embryo itself (*in Phys.* 313,21-7 translated below).

In order to illustrate this idea Simplicius compares the development of the embryo to the movements of a mechanical puppet (probably the θαύματα from Plato's *Republic* 514B), which are generated by an operator pulling a single cord. With these devices a simple linear motion is introduced into the system from outside, which is then translated into the complex dancing movements exhibited by the puppet as it passes through a network of internal gears. Simplicius chose this device (or so I shall argue) in order to illustrate what he took to be two important features of embryonic development: its *external* source of motion and its *internal* source of form.[49]

It is important to understand that the devices Simplicius has in mind are not the mechanical automatons Alexander uses as an embryological model. The difference in choice of device is philosophically significant. With Alexander's mechanical automatons, the role of the external agent is limited to being a catalyst. Once the operator sets the first part in motion the responsibility of moving the automaton is transferred to the network of gears inside the device itself. From this point on the automaton is moved by an *internally* generated motion (one axle moving another in a causal sequence). The philosophically interesting difference in Simplicius' choice of device is that *all* of its motions are generated by the external agent, not just the first:

> Consequently, in the human being, the λόγος of the generator has been anticipated and the offspring comes to be according to this, the father supplies, through his sperm, *both* the starting-point *and* the motion up to the end (just as in the case of the mechanical puppets: the operator supplies *both* the starting-point of

[48] I am grateful to Robert Todd for suggesting this translation.

[49] I am using 'form' here in the derivative sense to refer to the character or pattern of the movement, i.e. the developmental trajectory (see Peck 1993, xxxviii, §1), rather than the shape and form of the thing that results from it. The 'source of form', then, refers to the principle that imposes order and direction on the motion.

> the motion *and* the impulse to the end) according to the λόγος of the whole ordered process pre-existing within it, while the maternal nature is (even more proximately) productive of the form.[50] (Simplicius *in Phys.* 313,21-7)

Their different choices of device show that Alexander and Simplicius have quite different embryological models in mind. With Alexander's device the operator (and, by analogy, the father) only *initiates* the sequence, like the person who knocks over the first domino in a series. By contrast, Simplicius insists that the father not only starts the motion but continues to move the embryo right up to the end (μέχρι τέλους).[51] This is why he chose the mechanical puppet as a model for a developing embryo: unlike Alexander's automatons which move themselves after being let go, the devices Simplicius has in mind move only as long as the operator is pulling the cord (an *externally* generated motion). This is the first point of analogy Simplicius envisions between a mechanical puppet and a developing embryo: in both cases the external agent supplies *all* the motion; none of the motion is internally generated.

The reason for thinking Simplicius' νευροσπαστούμενα are mechanical puppets rather than marionettes (whose motions are also generated externally) has to do with his particular conception of nature. If I am right, Simplicius uses the mechanical puppet rather than a marionette to show how nature can be a source of *being moved* in a characteristic way while still *actively* participating in the production of the end result.[52] This is the second point of analogy.

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[50] This is of course quite *un*-Aristotelian. For Aristotle the father more properly supplies the offspring's form while the mother supplies the material which receives that form. To be sure, things are more complicated than this. For one thing *GA* 4.3 appears to assign the mother a direct role in producing formal resemblances to her side of the family (see, e.g., 768a14-21 where she is said to contribute a set of "demiurgic motions"). I provide a thorough account of Aristotle's reproductive hylomorphism in Henry 2004 (see esp. Chapter Four).

[51] Compare the description of Alexander's devices at 311,8 (ὥσπερ ἐν τοῖς νευροσπαστουμένοις τὴν ἀρχὴν τῆς κινήσεως ἐνδόντος τοῦ τεχνίτοῦ) with that of Simplicius' chosen device at 313,24-5 (ὥς ἐπὶ τῶν νευροσπαστουμένῶν ὁ τεχνίτης ἐνδίδωσι τὴν ἀρχὴν τῆς κινήσεως καὶ τὴν ἐπὶ τὸ τέλος ὁρμήν). This reinforces our claim that the model Alexander is using to illustrate biological development is a self-moving automaton, not a mechanical puppet. I suspect that Alexander's original text probably read ἐν τοῖς αὐτομάτοις θαύμασι (cf. *GA* 741b8-9) where Simplicius writes ἐν τοῖς νευροσπαστουμένοις.

[52] Moreover, nature is an *internal* principle, which finds no analogue in a marionette. There is another reason why Simplicius' νευροσπαστούμενα are most likely mechanical puppets rather than marionettes, whose relevance will become apparent in Part 4, though not currently relevant. One of Simplicius' objections against Alexander's

What Simplicius has in mind here can be seen by contrasting a mechanical puppet with a marionette, for example, Pinocchio.[53] Before Pinocchio became a real boy he was wholly dependent on Geppetto for his motion. This dependence is two-fold. In the first place, Pinocchio's limbs only moved when Geppetto moved them. In the second place, Geppetto also determined *the kind* of movements Pinocchio exhibited by manipulating strings attached directly to each of his wooden limbs. We can generalise this point by saying that a marionette is characterised by an *external* source of motion and an *external* source of form.[54] Alexander's mechanical automatons lie at the opposite end of the spectrum: the network of gears inside the device is an *internal* source of motion and an *internal* source of form. Simplicius' mechanical puppets fall somewhere in between these two: they have an *external* source of motion (the operator pulling the cord) but an *internal* source of form (the organisation of its gears).[55] The difference between a mechanical puppet and a mere marionette is subtle, yet philosophically important.

As I have said, a marionette is moved in all respects by the person manipulating its strings. In contrast to this, while the external agent makes the parts of a mechanical puppet move, he does not determine *how* they are moved. Rather, the kinds of movements exhibited by a mechanical puppet are determined completely by its internal structure. Here the single, linear motion generated by pulling the cord is transformed into a set of complex dancing movements as it passes through a system of mechanical gears. The philosophically significant point, then, is that with a mechanical puppet, even though all of the motion is *externally* generated, the form that that motion takes in the puppet derives from an *internal*

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concept of a mechanical embryo (one whose development is modelled on the movements of a mechanical automaton) was that it failed to capture Aristotle's point about natural generation being a *continuous* movement. As we shall see, Aristotle holds that in order for movement to be genuinely continuous it must be generated by a single common source of motion (*Physics* 8.10). Unlike a marionette, whose parts are moved independently of one another by working a different string (or set of strings), the movements of a mechanical puppet will satisfy this criterion: *all* of its movements derive from a single common source of motion (the operator pulling the master cord).

[53] Pinocchio was the character in the popular Italian children's story who was originally constructed by Geppetto as a wooden marionette but then later became a real boy.

[54] For this use of "form" see note 49 above.

[55] For the difference between the (active) gears of an automaton and the (passive) gears of a mechanical puppet see below.

principle rather than being constantly imposed on it from without as in the case of a marionette. In this way the mechanical puppet can be said to contribute actively to the production of its dancing movements without being an efficient cause of them.

A caveat is in order here. Mechanical puppets differ from marionettes in possessing internal gears; however, we need to distinguish these "passive" gears from the "active" gears inside an automaton. The latter generate motion in the automaton by moving one another in succession. As we have seen, Alexander takes the nature of an embryo (the internal source of its developmental motions) to be analogous to the active gears of the automaton. For Simplicius, nature is analogous to the passive gears inside the mechanical puppet, which contribute to the production of its dancing movements, not by *generating* that motion themselves, but by imposing the appropriate form and direction on motion introduced into the system from outside by the operator pulling the cord.

Simplicius' denial that Aristotle's concept of nature is a kinetic principle in the sense of causing motion is similar to an interpretation of Aristotle put forward recently by Gill.[56] Like Simplicius, Gill argues that for Aristotle the nature of an organism plays an active role in shaping its development, not by introducing new forces into the system (either by initiating causal chains or imposing physical constraints), but by regulating motions supplied by other factors. In other words, the embryo's nature is a principle inside the organism whose function is to co-ordinate a set of *already existing* motions in such a way that they reproduce the form of the thing that generated it.[57] Since the embryo's nature does not originate the motion it directs, Gill argues, that motion must be derived from some other source. For Simplicius (and here he differs from Gill) this is the role of the father, which was the first point of analogy with the mechanical puppet: in both cases the motive power is introduced into the system from outside by an external agent.

Gill suggests that, given the emphasis Aristotle places on the regulatory and directive function of an embryo's formal nature, we might compare it to a list of instructions that specify the different materials and tools

[56] Gill 1991.

[57] Gill compares the way the embryo's formal nature 'co-ordinates' motions to the way a recipe or set of instructions might be said to 'co-ordinate' the movements of the craftsman. I shall not comment on the legitimacy of this analogy here except to say that one would have to address the question of how exactly nature 'co-ordinates' or 'regulates' changes.

required to build the mature organism as well as the order, timing, and extent of operations to be carried out on those materials.[58] I suspect that Simplicius has something similar in mind at 313,21-7 when he speaks of "the λόγος of the whole ordered process".

At 313,15-16 (cf. 278,17) Simplicius says that nature reproduces its like for the sake of which it "anticipates" (προλαμβάνει; 313,22: προείληπται) all of the intermediate stages leading up to that end. Contrast this with Alexander's view that the specific path an embryo follows during the course of its developmental is determined at each point along the way by the nature of the antecedent state.[59] Against this, Simplicius argues that an embryo develops along a path which is "anticipated" by its nature at the start of development. What he means by this, I think, is that all of the important changes the embryo will undergo on its way to becoming a mature organism are specified beforehand in the λόγος of the whole ordered process pre-existing in it (cf. 313,21: ". . . in the human being, the λόγος of the generator has been anticipated and the offspring comes to be according to this"). This λόγος, which is the principle inherited by an offspring, is like a set of instructions or recipe for building the parent.[60]

Of course there is a sense in which Alexander also thinks the entire developmental trajectory from embryo to adult is "anticipated". For each change along the way ultimately depends on, and is causally determined by, the nature of the very first state from which all the others follow logically (the nature of *A* is to produce *B*, whose nature is to produce *C*, whose nature is to produce *D*, and so forth). Thus, the fate of the embryo is essentially fixed by the nature of that first state. The important point, however, is that for Alexander the change from one state to the next is

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[58] While I agree with Gill that the nature of a developing embryo has a regulatory or directive function and that in this sense it is like a list of instructions or recipe, I disagree with her central claim that nature does not *initiate* the motion it directs. I think it is quite clear in the *GA* that Aristotle takes an embryo's nature to *generate and control* the processes that make up development.

[59] Put another way, Alexander thinks the developmental trajectory of an organism is determined *in real-time* (i.e. 'epigenetically') as the process unfolds. The idea here is that what state the embryo moves into at time t_{n+1} (i.e. which part is generated at that point) depends on the particular nature of the state it occupies at time t_n and so is not determined until t_n.

[60] Simplicius seems to have borrowed this concept from the Stoics' *logoi spermatikoi* (cf. Plotinus *Ennead* V.7.1); however, a similar concept is at work in the *GA*. Lennox has coined the phrase "instructional inheritance" to describe Aristotle's theory of reproduction (Lennox 2001, 200).

determined, at least in one sense, at each point along the way by the nature of the immediately antecedent state (which is the source of that change) and not specified beforehand in anything like a recipe or set of instructions as Simplicius maintains.

There is one final point to make before turning to Aristotle's embryological model. As we have seen, Simplicius and Alexander agree that nature is responsible for the fact that development follows a teleological order without calculating each step in advance or looking to the form as a model (even if they disagree on how this idea is ultimately cashed out). However, Simplicius argues that nature is only *co*-responsible (συναίτιον) for this. For Simplicius, the mechanism of nature is itself a product of an Intelligent Designer who "co-ordinated its power in relation to the products it produces with knowledge of them both" (314,8-9). One way to interpret this idea is to connect it to the idea that the offspring comes to be according to "the λόγος of the whole ordered process". What Simplicius seems to be saying is that this λόγος (the developmental programme that nature executes in producing the offspring) was originally formulated by God. The idea, then, is that although nature builds the embryo without calculating each step in the process with a view to the end, the λόγος it follows was formulated by a rational agent (God) who *did* calculate those steps while looking to the Form as its model.[61] In this way the distinction between the two senses of "rational" that was so crucial to Alexander's account – acting with knowledge versus following an orderly sequence – collapses into the gnostic sense. For the (teleological) rationality of the sequence that nature follows ultimately derives from the (gnostic) rationality of its Designer.

Part 4. *Aristotle*

Aristotle's embryological model

Robert Todd has suggested that in comparing the development of an embryo to the movements of automatons Alexander is "drawing on Aristotle's

[61] Simplicius likely has the *Timaeus* in mind here. According to the *Timaeus* account, material necessities are συναίτια that produce the items of the physical world under the guidance of the Divine Craftsman. On the latter see Strange 1999 and Lennox 2001, 280-302 (esp. 293: "To call them [sc. material necessities] *sunaitia* is to describe them as operating and interacting according to a plan which is, however, not their own, much like the *productive* craftsmen are guided in their work by the *directive* craftsman.").

comparison of the action of male sperm on female matter to the action of puppets, at *de generatione animalium* II.1, 734b9-17 and II.5, 741b7-9".[62] While I agree with this in principle (save for the reference to "puppets"), it is important to point out that Aristotle deploys the analogy in connection with *two different* embryological phenomena. As we shall see, Alexander is only drawing on the second occurrence of the analogy.

Part of my aim in this final section is to challenge the standard interpretation of the *GA*'s use of automatons. Thus, before we begin, I should first say a word about this standard reading.

To my knowledge there is no comprehensive analysis of Aristotle's embryological use of automatons in the recent literature. However, it is possible to identify a common set of presuppositions that we might collectively refer to as the "traditional" or "conventional" reading.[63] The most widely shared of these is the assumption that the automatons Aristotle uses as an embryological model in the *GA* are the same mechanical devices used in *de motu* to illustrate animal motion (see T1).[64] This is generally accompanied by the assumption that the use of automatons in *GA* can simply be read off from their use in the *de motu*. Thus, it is almost universally agreed that the movements of automatons are used in *GA* to illustrate the idea of a causal sequence where the members of the series move one another in succession like a string of falling dominos. It is this view that I intend to challenge.[65]

Analogy 1

In the second half of *GA* 2.1 Aristotle introduces a puzzle concerning the moving cause of the embryo. His attempt at a solution consists of three successive arguments coming at 733b30-734b19, 734b19-735a4 (presented as a "fresh start"), and 735a12-b26, respectively. I shall only deal with the first argument of this triad. The main *aporia* driving this argument is how the father can be said to make the parts of the offspring if he is not

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[62] Todd 1982, 49.

[63] See, e.g., Nussbaum 1976, 146-52; 1978, 50-1, 347-8; Berryman 2002, 248-9; 2003,359; Todd 1982, 48-9. See also Platt's translation in Ross 1912 ad loc *GA* 734b16 and Farquharson's translation in Ross ad loc *de motu* 701b1-10.

[64] See, e.g., Lennox 2001, 245 *n.* 12: "The automata [from *GA*] are discussed in more detail in *MA* 701b1-13, where a detailed structural-functional analogy is drawn between them and the locomotive physiology of mammals".

[65] A reading similar to mine is hinted at, but not developed in Gotthelf 1997, 78 *n.* 23.

in direct contact with the matter at the time. Aristotle appeals to the example of a self-moving automaton in order to solve this puzzle (or one aspect of it):

T2. We must attempt to resolve this dilemma. For perhaps there is a statement of ours, made without qualification, which ought to be qualified, for example if we ask how exactly it is impossible for the parts of the offspring to be formed by something external. We see that in one sense it is possible, though in another sense it is not possible. On the one hand, it makes no difference whether we speak of the sperm or that from which the sperm comes[66] insofar as the former contains in itself the movement produced by the latter. On the other hand, it is possible for this to move this and for this to move this and to be like the automatons among the marvels. For the parts of an automaton, while at rest, somehow have present in them a potential (δυνάμις), and when something external moves the first thing, the next thing immediately comes to be in actuality (γίγνεται ἐνεργείᾳ). Therefore, just as in the case of automatons, in one way the external agent moves it, not by being in contact with any part of it at the time, but by having been in contact with it at one time. So too, that from which the sperm comes or that which made the sperm moves it having at one time been in contact with it, though not still being in contact with it. And in another way the internal movement moves it just as the process of building builds the house. (734b5-17)

The dilemma facing Aristotle in this passage (which is the result of a long and complicated argument) is the following. On the one hand, no part of the offspring can come into the female preformed inside the sperm after having been fashioned directly in the father (734b1-3); on the other hand, nothing external to the matter can make the parts (b3);[67] and yet it must be one or the other (b4; cf. 733b33-4). The second horn of this dilemma is the "statement" Aristotle refers to at the outset of our text (the one which "ought to be qualified"). His solution to the problem consists in showing that while it is not possible for the father to fashion the matter directly, it is possible for him to do this *indirectly* by moving the sperm: as Aristotle puts the point, "it is possible for this to move this and for this to move this".[68] This is supposed to resolve the dilemma because in this

[66] This is the sire's heart or, more generally, his nature (the source of which is the heart: 738b9-18, cf. 776b9).

[67] This follows from the contact proviso at 734a3-4 which states that if the agent is not in direct contact with the patient, it cannot set up motion in it, and if the agent does not set up motion in it, the patient cannot be affected by it.

[68] I will ignore the details of how exactly Aristotle thinks the father (or rather his nature) 'moves' the sperm, since it is not important for understanding the analogy. The *GA* will have some story to tell about this.

case it makes no difference whether we say *the sperm* fashions the matter or *the nature in the male* fashions it insofar as the latter moves the former.

Now Aristotle tells us that the phenomenon being investigated occurs just like the case of automatons:

> 1a) In one way the external agent moves the automaton, not by being in contact with it at the time, but by having at one time been in contact with it.
> 1b) In another way the automaton is moved by "the internal movement" (ἡ ἐνοῦσα κίνησις).

One of the first things we should notice about the analogy is that Aristotle never actually specifies what it is that is being compared to a self-moving automaton in T2: What are the embryological analogues of 1a and 1b?[69]

One reading takes these to be the father moving the sperm and the sperm moving the matter, respectively.[70] Here Aristotle uses the movements of automatons as a model for the entire process of reproduction beginning with the production of sperm in the father. Thus, the analogy will look something like this:

operator	→	first part	→	second part
father	→	sperm	→	menstrual fluid

The problem with this first reading is that the analogy in T2 clearly involves *one* thing being moved in *two* ways: in one way (τρόπον μέν) the thing in question is moved by the external agent; in another way (τρόπον δέ) it is moved by an "internal movement". Given the structure of the analogy, Aristotle must be comparing the movements of an automaton either to the development of the embryo or to the movements of the father's sperm in fashioning the menstrual blood inside the female.

Peck takes the former reading. According to Peck, Aristotle uses the automaton in T2 as a model for a developing embryo: in one way that from which the sperm comes (or that which makes the sperm) causes the embryo's development; in another way it is the movement occurring

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[69] This is something that is concealed by most English translations, which inevitably end up offering what amounts to the translator's own interpretation of Aristotle's point. I have attempted to preserve the ambiguity that exists in the Greek in my own translation.

[70] Platt (in Ross 1912 ad loc *GA* 734b5-17) compares the father moving the sperm to the watch-maker pushing the first wheel inside the watch (= 1a) and the other wheels moved by the first to the parts developed by the sperm (= 1b?). See also Katayama 1999, 82.

within the embryo that moves it just as the process of house building builds the house (cf. 730b5-8).[71] While it is clear that Aristotle is comparing the development of an embryo to the movements of an automaton in the second occurrence of the analogy (see T3 below), this cannot be what he's doing here. For the first way in which the thing in question is said to be moved is by having at one time been in *contact* with the father's nature (that which makes the sperm), the source of which is his heart. This means that the first part of the analogy (1a) at least is targeting the movements of the sperm, not the development of the embryo. For the material out of which the embryo develops (the residue supplied by the female) has never been in direct contact with the sire's heart and so could not have been moved in this first way. Indeed, it is precisely this fact that generates the puzzle in the first place.

Since the analogue of 1a must be the sperm (the embryo having never been in contact with that which makes the sperm), the analogue of 1b must be as well. For, as we have seen, the analogy involves *one* entity being moved in *two* ways. This yields the following reading. What Aristotle is saying is that the sperm's movements in fashioning the matter can be compared to a self-moving automaton:

2a) In one way the nature in the male moves the sperm, not by being in contact with it at the time but by having at one time been in contact with it.
2b) In another way the internal movement moves the sperm.

As I read the analogy, Aristotle brings in the example of a self-moving automaton, not to show how the father makes his contribution to generation per se (as the first reading holds), but rather to show how the sperm can continue to move once it is no longer in contact with the father *and* how the father can still be said to fashion the matter without being in contact with it.[72]

The explanandum in T2, then, is the sperm's movements in fashioning the embryonic materials, which takes place inside the female. I have argued that the proper way to read the analogy is to take Aristotle as

[71] Peck 1993 ad loc *GA* 734b14-16 reads, "so too that from which the sperm originally came, or that which fashioned the sperm, <causes the embryo's movement> . . ." (see also Peck 1993, 151 *n.* d: "*i.e.*, development"). This is how Alexander would understand the analogy (though I do not think he had this one in mind). Cf. Berryman 2002, 249.

[72] In this way I suspect that the automaton analogy in T2 is meant to improve on the earlier analogy with the movements of the builder's tools at *GA* 730b9 ff.

saying that *in one sense* the sperm is moved by the nature in the male while *in another sense* it is moved by an internal motion. The former allows Aristotle to say that it is the father moving the matter, while the latter is the feature in virtue of which the sperm can be said to move itself. The question is whether this can be understood in terms of the *de motu* analogy as traditionally assumed. Can T2 be assimilated to T1?

Now the mechanical automatons from the *de motu* analogy could be used to illustrate the idea of being moved by an internal motion (1b). Here the internal motion would be the movement of the gears: one axle moves another in succession and in virtue of this moves the automaton along. However, Aristotle would ultimately reject the idea of mechanized sperm.[73] For sperm does not contain any mechanical parts that could function as 'gears'. On the other hand, we have already seen that when it comes to locomotion Aristotle does accept the idea of a mechanized animal. Indeed, as we have seen, the analogy between the movements of animals and the movements of automatons depends on this biomechanical picture (the fact that an animal is equipped with internal parts that function like the gears inside the automaton).

The disanalogy between the sperm and the mechanical automaton is much less benign than it may first appear. For it undermines the ability of the mechanical automaton to serve as a model for the sperm's self-motion. The problem is that the automaton's self-motion is *explained by* the movement of its gears: one axle moves another in a sequence *and in virtue of this* moves the automaton along. If there are no mechanical parts inside the sperm moving one another in succession, then its own self-motion will be left unexplained.

Serious problems also arise for the standard reading of T2 when we consider the first feature of the analogy (1a): the external agent. Aristotle compares the nature in the male to the external agent who moves the parts of the automaton "not by being in contact with any part of it now, but by having been in contact with it at one time". The way to understand this, I think, is to take the external agent as somehow being responsible for the *internal motion* that moves the automaton after it has been released; it is in this way that the external agent can be said to move the parts of the

[73] A "mechanized" sperm would be one whose internal motion is literally the motion of one internal part moving another in succession like the gears inside the mechanical automaton. As we shall see, Aristotle equally rejects the idea of a mechanized embryo (and here Simplicius seems to be following Aristotle).

automaton without being in contact with them at the time. But who is the external agent that moves the automaton in the *GA* analogy?

In the *de motu* analogy the external agent is the operator who triggers the automaton's movements. However, we must be careful how we understand this. The tendency among commentators is to imagine the operator moving the parts of the automaton by moving the first part *A*, which in turn moves the next part *B*, and so forth like a string of falling dominos. The idea is supposed to be that the operator moves *B* without being in contact with it (and likewise for the other parts) in the way the person who knocks over the first domino in the series can be said to move the later ones, viz. transitively.[74] Even if this were right, it is not clear that causing motion transitively in this way would be robust enough to solve the problem Aristotle is confronting in T2, namely how the father can be said to move the embryonic materials without being in contact with them.

Ultimately this is a moot point. For if we turn back to T1, we can see that the way the operator moves the parts of a mechanical automaton is by releasing a set of weighted cables which triggers a causal sequence inside the device (one axle moving another in a chain); the sequence set going by the operator will be the internal movement that moves the parts of the automaton after it has been let go.[75] Here we encounter the problem. According to *Physics* 8.4, the operator who releases the cables will only count as an *accidental* cause of the automaton's movements: "The thing in a sense *is* and in a sense *is not* moved by the one who moves what is obstructing or preventing its motion – e.g. the one who pulls away a pillar or removes the stone from a wineskin in the water is the accidental cause of motion . . ." (255b23-9). Moving the automaton by freeing a set of weighted cables is analogous to moving the roof of the temple by removing the pillars that were holding it up: in both cases the person causes motion κατά συμβεβηκός or accidentally. And this is hardly the

[74] Cf. Berryman 2002, 249.

[75] These would correspond to 1a and 1b, respectively. Berryman's description of Hero's robots provides an excellent illustration of the current point: "The robot is in fact a little silo on wheels, with an upper and a lower chamber separated by a trap door: as the millet trickles down once the trap door is opened, the weight falls. The operator can open the trap door ahead of time, and the time lag before the device starts moving means that he is not directly manipulating the device – indeed, he can be out of sight – at the time when the device begins to move" (Berryman 2002, 245). Here the operator moves that device, not by directly moving its first part, but simply by opening the trap door.

sense in which Aristotle thinks the father can be said to move the embryonic material in T2.

It seems clear that *if* Aristotle is comparing the sperm to a mechanical automaton (as has been traditionally assumed), then he must be comparing the father to the engineer who constructs the device rather than the operator who triggers its motion. For only the engineer could be said to move the parts of the automaton without being in contact with them in the non-accidental sense insofar as he is responsible for the mechanism that generates its internal motion (he configured its network of gears, which is the internal principle that moves the device after being released). However, as we shall see, there is good reason to suspect that T2 is not referring to the same mechanical automatons used in T1 after all.

Analogy 2

The second occurrence of the analogy with automatons comes in *GA* 2.5. Here the target is the process of development:

> T3. The parts of the embryo already exist in the matter potentially, so that once a source of motion comes to be they develop in an uninterrupted sequence like the marvels that move of their own accord. And the meaning of the statement which some of the natural philosophers make, "proceeding towards its like", must be taken, not as saying the parts are moved in the sense of changing place, but as remaining in place and undergoing alteration in softness and hardness and colour and with respect to all the other differences in the uniform parts, becoming actually what they previously were potentially. (*GA* 741b7-15)

Influenced by the *de motu* analogy, scholars have traditionally assumed that Aristotle is comparing the movements and changes initiated in the menstrual blood by the sperm to the causal sequence set off inside the mechanical automaton. As we have seen, this interpretation goes all the way back to Alexander. Yet, while it is certainly tempting to read T3 in this way, Alexander's interpretation must be resisted.[76] As we shall see, Aristotle's statement about the parts of animals developing in a sequence like the movements of automatons cannot be assimilated to the *de motu* analogy as has been traditionally assumed.

There are two main reasons why Aristotle's embryological use of automatons in T3 cannot be read off from their use in *de motu* (T1). First, bio-

[76] In what follows I shall discuss Alexander's reading of the automaton analogy as set out in Part 2 of this paper. However, what I have to say will clearly have implications for the traditional interpretation found in the recent literature.

logical development (on Aristotle's theory) does not exhibit the central feature of the *de motu* analogy. Unlike Alexander, Aristotle does not think the process leading from embryo to adult is a *causal* sequence.[77] Second, there is reason to suggest that the sequence of events set going by the operator in *de motu* does not qualify as one continuous motion. If this is right, then Aristotle cannot be referring to the movements of a *mechanical* automaton (as Alexander thinks), since their movements do not exhibit the essential feature of development being illustrated in T3.[78]

The first disanalogy highlighted here (the fact that the development of an embryo is not a causal sequence) is stated explicitly in the argument leading up to T2. After showing that the parts of an organism develop in an ordered sequence (ἐφεξῆς) "like the plaiting of a net" (734a19), Aristotle asks what kind of sequence development is:

> But since one part is earlier and another later, is it the case that the one *produces* the other and exists on account of the thing next to it [$A \rightarrow B \rightarrow C$], or rather is it more the case that the one comes into being *after* the other [*A, B, C*]? By this I mean, for example, *not* that when the heart comes into being it produces the liver and the liver in turn produces something else, but the one comes after the other *but not by its agency* (just as the man comes into being after the boy). The reason <why development is not a causal sequence of the first sort> is that in the case of things that come to be by nature or art that which exists potentially is produced by that which exists actually, so that <if one part is produced by another> the shape and form <of the later part> would have to be in <the earlier part>, e.g. the shape and form of the liver would have to be in the heart. And this account is strange and fantastic in other ways too. (734a25-33)

As we have seen, the assumption that biological development is a causal sequence was seen by Alexander as one of the essential points of analogy with the movements of a mechanical automaton. Indeed, the idea that each thing that comes into being in the course of development is "productive of and capable of setting in motion" the one that comes after it crucially underlies Alexander's understanding of that analogy. However, Aristotle here insists that the development of an embryo is not a sequence of this sort: it is *not* the case that the heart makes the liver and the liver

[77] As we have seen, being a causal sequence is precisely what allows Aristotle to assimilate animal locomotion to the movements of a mechanical automaton (the process leading from the perception of an object of desire to the appropriate bodily response is a case of one thing moving another in succession).

[78] For more on this reading of T3 see below. The second point is meant to block the objection that Alexander was right in his *choice* of embryological model but simply diverges from Aristotle in how he deployed it. I shall return to this below.

makes something else and so forth in a chain. The fact that the process of biological development does not follow the same pattern as the movements of a mechanical automaton – it is not a chain of causes and effects – thus severely undermines Alexander's interpretation. Indeed, Aristotle all but rejects the comparison with mechanical automatons here as "strange and fantastic".

One of the reasons Aristotle thinks development cannot be a causal sequence is that it would violate the principle that what is potentially *X* can only be made actually *X* by what is already *X* in actuality: in order for the heart to produce the liver it would already have to *be* a liver in actuality ("the form and shape of the liver would have to be in the heart"), which is absurd. What is interesting is that Simplicius uses this very same objection against Alexander at *in Phys.* 312,34-313,1: "Again, everything that comes to be actually *X* out of what is potentially *X* is brought to that state by that which is *X* in actuality. If, then, the shoot is not stalk in actuality, it could not produce the actual stalk".[79] The fact that Simplicius, like Aristotle, deploys this principle to show that development cannot be a causal sequence as Alexander proposed raises interesting questions about just how familiar he was with the details of Aristotle's biological works.

The other disanalogy between the development of an embryo and the movements of a mechanical automaton is that the latter are not one and continuous. If this is right, then we have a further reason for thinking that (pace Alexander) the automatons Aristotle uses as a model for a developing embryo in the *GA* are not those same mechanical devices he used in *de motu* to illustrate animal locomotion.[80]

Now I take it that when Aristotle says the parts of animals develop in an "uninterrupted sequence" (συνείρεται τὸ ἐφεξῆς), he means that the process leading from embryo to adult is one continuous change rather than a collection of discrete changes.[81] As Simplicius points out, because Aristotle defines change in terms of the actualisation of a potential, the process of development, if it is to be considered *one continuous* change, must be the actualisation of *one* potential. As such, Simplicius argued, the nature in

[79] Simplicius' concept of nature as a potential for the formation of a unified whole is consistent with Aristotle's principle here. For in this case it is the nature of the human being (who is actually a human being) that is responsible for bringing the embryo (which is potentially a human being) to a state of actuality.

[80] Below I shall suggest that there is a sense in which they are the same devices (see note 85 below).

[81] Cf. Lennox 2001, 232; Gotthelf 1987, 219 *n.* 30.

the embryo must be a single potential for the formation of the organism as a whole and not a succession of distinct potentials for the formation of individual parts as Alexander suggested.

Aristotle makes a similar point in *Physics* 8.10 in connection with the movements of projectiles.[82] At 267a10-25 Aristotle suggests that because a causal sequence of this kind involves a number of consecutive movers ($A \rightarrow B \rightarrow C \rightarrow D$), the motion will not be genuinely continuous but only appear so (φαίνεται). In order for motion to be considered one and continuous, Aristotle argues, there must be *one* thing being moved by *one* mover. This idea is repeated towards the end of the chapter where the absence of a single common source of motion is explicitly identified as the reason why a causal sequence cannot be considered one continuous motion:

> But there is a difficulty in supposing it to be possible for anything that is in motion to move continuously and not merely in the way in which it is caused by something repeatedly pushing it, in which case the continuity <of its motion> amounts to no more than successiveness. Such a mover must either itself continue to push or pull <the thing> or perform both these actions, or the action must be taken up by something else and be passed on from one mover to the next (just as we described earlier in the case of things thrown, since the air, being divisible, is a mover in virtue of the fact that different parts of the air are moved, only one after another); and in either case the motion cannot be a single motion, but consecutive motions. (267b9-17, translated after Hardie and Gaye)

Although Aristotle only mentions the case of projectiles here, his scepticism about the continuity of motion can be extended to any causal sequence involving a system of moved movers where the action of the first mover is "taken up by something else" and "passed on from one mover to the next" in succession.[83] This includes the movements of a mechanical automaton. If this is right, then when Aristotle tells us that the parts

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[82] On Aristotle's theory of projectile motion different parts of the air move one another in succession and in virtue of this move the projectile along. This is conceptually identical to the analysis of mechanical automatons in *de motu*: different parts of its gear-system move one another in succession and in virtue of this move the automaton along. The parallel nature of these two phenomena will thus allow us to extrapolate from the movements of projectiles to the movements of automatons, even if Aristotle himself does not do this.

[83] The fact that projectile motion is non-natural does not affect the argument here. For the general point is that the continuity of motion amounts to no more than successiveness in cases where the action of the first mover is taken up by something else and then passed on from one mover to the next in a causal sequence. It makes no difference whether the action is one mover pushing another or one mover generating another by means of an internal principle of change (natural motion).

of an embryo develop in a continuous sequence like the movements of automatons, he cannot be referring to the same mechanical devices used in *de motu* to illustrate the biomechanics of animal motion. For this is not a point of analogy with those devices.

Note that unlike Alexander's chosen device, the movements of Simplicius' puppet *do* satisfy the criterion for being one and continuous insofar as they all derive from a single common source of motion (the operator pulling the master cord). However, this is an *externally* generated motion, which is inconsistent with Aristotle's analysis of the process of biological development. Here Aristotle would be in full agreement with Alexander against Simplicius in holding that the motion must be generated from an *internal* principle (e.g. *Physics* 2.8, 199b13-18). Thus, despite all of their differences, it is important to stress that Aristotle and Alexander agree on one fundamental point: the self-moving automaton provides a better embryological model than Simplicius' mechanical puppets, even if they do not agree on what *kind* of automaton provides the ideal model.

What are the GA automatons?

In T3 Aristotle tells us that the parts of animals develop in a continuous sequence "like the marvels that move of their own accord". I have argued that these cannot be the same devices Aristotle used in *de motu* (T1) as traditionally assumed. For those mechanical automatons do not exhibit the essential feature of biological development being illustrated in T3 (their movements are not one and continuous). The obvious question is, If Aristotle is not referring to mechanical automatons in the *GA* (as Alexander seems to think), then what kind of self-moving automaton is he referring to?

First of all, if we assume that Aristotle has the same kind of automaton in mind in both *GA* analogies, then if the automatons in T3 are not the mechanical devices from *de motu*, those used in T2 as a model for sperm will not be either. I want to suggest that what Aristotle is referring to in the *GA* are automatons like those used in *de motu*, but ones whose internal motion is the actualisation of a single potential rather than a causal sequence passing through a series of mechanical gears.[84] However, this doesn't mean he is referring to some other *actual* device; indeed, none of the devices available at the time seemed to have suited his purposes (especially in T3). Rather, what Aristotle has in mind in *GA* is a *hypo-*

[84] This is the direction in which Gotthelf 1997 seems to have been heading.

thetical version of the automaton he used elsewhere to illustrate the phenomenon of animal locomotion.

The use of hypothetical models based on more familiar artefacts to explain natural phenomena is not uncommon in Aristotle. For example, at the end of *Physics* 2.8 he compares the developing embryo to a self-building ship in order to make the point that the nature in the organism operates without being aware of the goal towards which it advances. Clearly Aristotle is not referring to any actual ship. Rather, he is asking us to imagine a familiar artefact with a hypothetical modification: imagine the materials for the ship contained the shipbuilding art in themselves – nature is like that. I am suggesting that Aristotle likewise employs a theoretical, rather than a strictly empirical, model in T2 and T3.[85]

To close this discussion I want to suggest that, while the state of the art at the time would have been too impoverished to supply Aristotle with exactly the kind of device he was after, modern technology has proven to be more fruitful. Aristotle's ideal embryological model would be a device that is moved by an *internally* generated *continuous* sequence, that is, one whose movements are generated by a single common source of motion inside the device itself. None of the technological devices available to Aristotle seem to meet this criterion. For example, the mechanical automatons that Alexander thinks Aristotle used for his embryological model (those from *de motu*) are moved by an internally generated *causal* sequence: one axle moves another in succession, which makes the parts

[85] Two features from the description of the automatons in T2 support this assessment. First, there is no mention of any sort of physical mechanism inside the automaton like the cables and axles mentioned in the *de motu* analogy. Rather, the source of the automaton's movements in T2 is said to be a δυνάμις or "potential". Second, Aristotle speaks of one part "coming to be in actuality" (γίγνεται ἐνεργείᾳ, 734b12-13) after another rather than one part *being moved* by another, which is what we should have expected if Aristotle were simply employing the same model from *de motu*. (See Peck ad loc *GA* 734b12-13.) Together these two features suggest that the movements of the automatons being described in T2 (and T3) come to be as part of the actualisation of a single potential for motion rather than mechanically by means of a causal sequence passing through a network of physical gears (like those in T1). It is unlikely that the state of the art at the time could have provided Aristotle with anything approximating this idea (though a modern computer might: see below). My suggestion is that instead Aristotle simply held up the mechanical device he used in his lectures on animal motion and said, 'Imagine this device except instead of mechanical gears imagine its movements were all generated by a single δυνάμις inside it'. (So there is a sense in which he has those *de motu* devices in mind.)

of the automaton move. On the other hand, Simplicius' mechanical puppets exhibit *externally* generated continuous motion: all of its movements are generated by an operator pulling a single master cord.[86]

In contrast to this, a pre-programmed automaton in the modern sense (one that owes its movements to the execution of a computer programme) could supply Aristotle with the kind of device he needs. This device has several advantages. First, the movements of a pre-programmed automaton are one and continuous in the required sense: all of its movements are generated by a single common source of motion inside the device itself (the computer programme). Second, the execution of a programme is precisely the kind of non-causal sequence of which development is said to be an instance (*GA* 734a25-33): the movement of each part owes its existence to the execution of a single developmental programme and not to the agency of each other. Finally, a pre-programmed automaton would provide Aristotle with a much better spermatic model. In this case the nature in the male could be said to control the sperm's movements, not by being in contact with it at the time, but by having *programmed* those movements into it at the start. Moreover, we do not encounter the problem of a "mechanized" sperm, since the internal motion that moves our modern automaton is not a causal sequence passing through a network of physical gears but the execution of a programme, which for Aristotle would be the actualisation a single potential for the whole ordered process.[87]

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[86] Marionettes are the least ideal model: they are neither self-moving nor do they exhibit continuous motion (the different parts are moved by the puppeteer moving different strings). Nor could the example of projectiles have supplied any kind of model for a developing embryo: projectiles are moved by an *externally* generated *causal* sequence (one part of the air moves another and in virtue of this pushes the projectile along).

[87] In the end even the computer model will ultimately fail to capture at least Aristotle's account of development because of the way he understands the concept of nature. For Aristotle an embryo's productive nature is an internal principle that generates *and* controls the sequence of changes that make up the process of its development. Strictly speaking, however, a computer programme is not a source of motion but only a set of instructions; the processor is the internal principle that supplies the necessary activity for executing those instructions. I am grateful to Robert Henry for pointing this out to me.

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