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Thomistic Reflections on Teleology and Contemporary Biological Research

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Abstract

Modern biologists often claim to be committed to a strong reductionist conception of scientific explanation, in contrast to the teleological explanations of medieval natural philosophers. Attention to the actual explanatory strategies used in contemporary biological research, however, reveals a dependence on final cause explanations. A good example can be found in adaptation studies where explanation is typically in terms of optimal design models. Such optimality models are teleological precisely in the way Thomas Aquinas and Albertus Magnus insisted explanation of natural forms must be. Consequently, the non-reductionist conception of final cause defended by Neo-Aristotelian philosophers of science is entirely consistent with common modes of explanation used by contemporary biological researchers.

Keywords

Albertus Mangus, Thomas Aquinas, biology, teleology

1. Introduction

In his commentary on the *Posterior Analytics*, St. Albert the Great remarks that Aristotle is quite right in claiming that unqualified understanding of the subject of scientific research is possessed only when the investigator knows the cause of the subject. Albert then adds:

> We say "when we understand the *cause*," not *causes* in the plural, because there is one originating cause which is the cause of causes, this is the end through which above all something is known. This is because each thing is determined and known with respect to its maximal end [*maxime fine*] and its essential optimal state [*optimo essentiali*]. Cause is said in such a way that it is understood as one with respect to the subject, for there are three things which together

> constitute the beginning of knowing: the productive agent, the form, and the end, as Aristotle says in the second book of the *Physics*. Although there are many causes of any given thing, one cause is always the completing cause, which is the cause above all, and it is with respect to that completing cause that it is said: knowing is when we understand the cause.[1]

Albert's student, St. Thomas Aquinas, understands Aristotle's scientific method in the same way, for he points out that, because nature always acts for the sake of something, research must consider the end as well as the form of its subject.[2] The ultimate goal of scientific research, says Thomas, is to demonstrate that something is true because it is better that it be so and he proceeds to provide the common Aristotelian example of the benefit to carnivorous animals of the food-cutting capacity of sharp incisor teeth.[3]

Albert and Thomas are here presenting a strictly Aristotelian notion of scientific explanation. In response to a puzzle that arises out of observation, the scientific investigator initiates a research program in an attempt to solve the puzzle. The program proceeds through a series of dialectical techniques aimed at discovering the causes of the subject of the puzzling observation. The puzzle is finally solved when the causes of the subject are demonstrated. Yet, such demonstration is incomplete and the subject of research is not fully understood until all the causes are resolved into the final cause that explains that for the sake of which the subject is caused to be the way it is. Using the example of Aristotle cited by Thomas, we can roughly illustrate the method.[4] Puzzled by the observed presence of sharp incisors in meat-eating animals, the zoological investigator proceeds to solve the puzzle by discovering the reason why such a form exists in these

[1] "Cum autem dicimus cum *causam* cognoscimus, non *causas* in plurali: ideo quia una est principalis causa, quae est causa causarum, quae est finis, per quam potissime scitur; quia unumquodque maxime fine suo et optimo essentiali determinatur et scitur. Dicitur etiam causa ut subjecto intelligatur una: quia tres quae principium sunt sciendi, in unam coincidunt, efficiens et forma et finis, ut dicit Aristoteles in secundo *Physicorum*. Ad huc autem quamvis multae sint causae alicujus, una autem semper est completiva quae potissime est causa, et ad illam respiciendo dicitur, quod scire est cum causam cognoscimus." *Posteriora analytica* I, tr. 2, c. 1 (*Opera omnia*, ed. A. Borgnet [Paris, 1890] 2:23a).

[2] ". . . et quia natura operantur propter aliquid, ut infra probabitur, necesse est quod ad naturalem pertineat considerare formam non solum inquantum est forma, sed etiam inquantum est finis." *Expositio in libros Physicorum Aristotelis* II, lect. 11 [246] (ed. Marietti, pp. 118–19).

[3] "Et dicit quod etiam naturalis demonstrat aliquando aliquid esse, quia dignius est quod sic sit; sicut si demonstret quod dentes anteriores sunt acuti, quia melius est sic esse ad dividendum cibum, et natura facit quod melius est." *Expositio in Physicorum* II, lect. 11 [249] (ed. Marietti, p. 119).

[4] *Parts of Animals* III, ch. 1 (661a34f); Albert, *De animalibus* XII, tr. 3, c. 6 (tr. Kitchell and Resnick, p. 975).

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animals. Through detailed studies of the material composition of the teeth, of incisor morphology, and of the developmental processes by which they come to be in the animal's mouth, the investigator gathers and sorts out the data relevant to the explanation of carnivore incisors. The explanation is achieved when all these causal elements are understood in terms of the unifying element of incisor function. In order to be nourished by meat, an animal must initiate the digestive process by cutting off manageable morsels of meat that can then be broken down by other means available within the body. The sharp-edged morphology of incisors, their material composition, and their growth are understood as being for the sake of this cutting function. Moreover, the animal performs this meat-cutting function by means of incisors for the sake of being nourished by meat.

A teleological account of the subject of scientific investigation not only reveals a true cause of the subject, but also unifies all the other true causes in a single intelligible account of the subject. In this way, final cause is central to any research program, for through the demonstration of the final cause the investigator is able to understand why the subject is formally and materially constituted in the way it is as a result of certain natural agencies. Without such final cause explanations, the researcher possesses only a partial and disjointed account of the subject. Indeed, from an Aristotelian point of view, where there is no teleological account, there is no true scientific explanation. Any scientific account that is limited to a list of the material components of its subject and references to the processes at work upon and within such components is merely the beginning of explanation. If research is not extended to the discovery and demonstration of the subject's final cause, then research is incomplete and not yet fully scientific.[5]

If Albert and Thomas are right about this, then one would expect to find in modern biological research programs a clearly delineated effort to discover the final causes of organisms. In fact, one would expect contemporary investigators to have developed techniques designed to unify all the material and mechanical information concerning observed organic forms into a single overarching causal account that is teleological in nature. Is there anything in modern biological research that corresponds to this Aristotelian conception of scientific explanation? Do there exist any modern research programs in which final cause explanation plays an explicitly unifying role? These questions take on special interest for Neo-Thomists because of the rejection of teleology by many modern biologists and philosophers

[5] For a classical Aristotelian account of a scientific research program see my 'Albert the Great and the Revival of Aristotle's Zoological Research Program', *Vivarium* 45 (2007), pp. 30–68.

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of science.[6] Thus, in connection with these questions we can raise yet another: Can attention to the traditional Aristotelian conception of scientific explanation provide a clear philosophical account of the structure and techniques commonly used in contemporary biological research programs?

That the answer to all these questions is 'yes' goes a long way toward showing the continued relevance of the insights of medieval Aristotelians such as Albert and Thomas regarding the nature of scientific knowledge. Further, by attending to the ways in which modern biological research proceeds in the manner set out by Aristotle and his followers, the central role of teleology in our knowledge of nature is confirmed. Adaptation studies in contemporary biology provide particularly clear and evocative examples research programs in which final cause plays an explicit unifying role in explanation. A close look at a common explanative strategy used in zoology and botany reveals the manner in which teleology enters into contemporary research programs. It will also provide the basis upon which a response can be made to those who would deny a role to final causes in scientific explanation.

Following Darwin, contemporary researchers typically focus on adaptation insofar as they view the environment as posing problems that organisms need to solve in order to survive and flourish.[7] Adaptation is the natural process by which organisms effect these solutions and the end or goal of the process is a well-adapted organism. Teleology, then, is at the heart of the Neo-Darwinian conception of organic fitness and research aimed at discovering the causes of that fitness must, as the Aristotelians point out, consider final causes. A particularly provocative example of how close modern research procedures are to the method prescribed by Aristotle and his followers is optimal design modeling. A popular explanatory strategy among orthodox Neo-Darwinians involves the construction of an "engineering" model of the optimal adaptive strategy for an organism's flourishing in a specified environmental niche. Given certain assumptions about the functional requirements of the organism in question, its optimal design should provide the explanation for its flourishing in that environment. The model becomes a test through a comparison with the actually observed morphologies or behaviors of the species under study. If the fit between model and morphology or behavior is a good one, that is taken as presumptive evidence of the claim that the morphology or behavior is an adaptation for that environment. It can be said without anachronism that Aristotle and his followers also

[6] For discussion see Michael Ruse, *Philosophy of Biology Today* (Albany, 1988), especially pp. 43–49 and Ernst Mayr, 'The Idea of Teleology', *Journal of the History of Ideas* 53 (1992), pp. 117–35.

[7] Richard Lewontin, 'Adaptation', *Scientific American* 239.3 (1978), pp. 212–30.

made pervasive use of optimal design strategies in their explanations of animal morphologies and behaviors. No less than Neo-Darwinians, Aristotelians are concerned to explain organic structures as being for the sake of some functional contribution to the organism's being or well-being.[8]

Optimal design explanations are not without their problems and inherent dangers. Indeed, recent discussions in the literature have become rather heated over such issues as the presumptive bias of optimal designs and the sometimes *ad hoc* appearance of 'engineering' models.[9] Even the degree to which optimality models contain measurable or otherwise testable features has been brought into question.[10] None of these problems demonstrate that the use of optimality models will necessarily result in flawed explanations or otherwise create methodological pitfalls. Yet they do indicate that care must be taken with such teleological accounts in order to avoid excesses and preserve a valid mode of explanation. No less than his modern counterparts, Aristotle was aware of such potential methodological problems and the danger of accidental accounts masquerading as proper causal demonstrations. Partly because of his limited access to the data and incomplete knowledge of foundational structures, Aristotle did not always avoid such difficulties in his own teleological accounts of animal morphology and behavior.[11] Nonetheless, he was able to make some crucial distinctions and develop some methodologically sound procedures aimed at making optimality arguments properly explanatory.

The purpose of the present study is to locate the place of optimal design explanations in an overall Aristotelian scientific method, such as that defended by Albert and Thomas. This will be accomplished first of all by briefly describing optimality models in terms of their structures and applications. Following this, optimality models will be discussed in the context of the general structure of Aristotelian

[8] See my 'Neo-Darwinians, Aristotelians, and Optimal Design', *The Thomist* 62 (1998), pp. 355–72.

[9] The classic critique is that of Stephen J. Gould and Richard C. Lewontin, 'The Spandrels of San Marco and the Panglossian Paradigm: A Critique of the Adaptationist Programme', *Proceedings of the Royal Society London* B205 (1979), pp. 581–98. See also the contributions to *The Latest on the Best: Essays on Evolution and Optimality*, ed. J. Dupré (Cambridge, Mass., 1987).

[10] See, for example, Steven Hecht Orzack and Elliott Sober, 'Optimality Models and the Test of Adaptationism', *The American Naturalist* 143 (1994), pp. 361–80 and the reply by Robert N. Brandon and Mark D. Rausher, 'Testing Adaptationism: A Comment on Orzack and Sober', *The American Naturalist* 148 (1996), pp. 189–201.

[11] There is evidence that a debate over such problems was carried on within the Aristotelian tradition. See James G. Lennox, 'Theophrastus on the Limits of Teleology' in *Theophrastus of Eresus: On His Life and Work*, ed. W. W. Fortenbaugh, P. M. Huby, and A. A. Long (New Brunswick: Rutgers University Studies in Classical Humanities, 1985), v. 2, pp. 143–63.

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scientific method. Finally, some comments on the nature of Aristotelian final causes will be offered and briefly discussed in light of the modern critiques of teleology. The value of developing an Aristotelian account of adaptation is twofold. First, an Aristotelian account of optimality models will serve to ground the modern adaptationist program in a traditional ontology foundational to a realist philosophy of science. Second, the extensive critical investigations and conceptualizations of teleological explanation developed by Aristotelian natural philosophers provide distinctions important to understanding the role of final cause in contemporary scientific research. On the basis of these distinctions, a response to modern critics of teleology can be formulated.

Far from the naive panglossianism attributed to Aristotelians by some of their modern critics, their formulations of what it means for a biological form or process to be 'for the sake of something' were notably naturalistic.[12] They were aimed at providing a causal account of the observed adaptations of organisms in their natural environments. It was clear to Aristotle that empirical description, although necessary, was not enough. In his treatise on animal respiration, he notes that a major reason for his predecessors' failure to provide a properly scientific account of respiratory activity was *both* a lack of experience with the internal parts *and* a failure to grasp that nature always acts for the sake of something. He not only criticized them for failing to provide sufficient morphological descriptions of lungs and gills, but also for failing to investigate why such parts are present in the first place.[13] It has been noted by several scholars that such passages show Aristotle's concern to steer a middle course between the Scylla of Democritean reductive materialism and the Charybdis of Platonic demiurgic teleology.[14] Such a balanced understanding of scientific method that insists on explanation in terms of essentially naturalistic causes without resorting to simple reductionism is entirely relevant to recent attempts to develop realist philosophies of

[12] The extensive recent literature on Aristotle's teleology has emphasized its naturalism; see Allan Gotthelf, 'Report on Recent Work and an Additional Bibliography' appended to David M. Balme's translation of *De partibus animalium I* and *De generatione animalium I* (Oxford, 1992); see also Gotthelf's 'Understanding Aristotle's Teleology' in *Final Causality in Nature and Human Affairs*, ed. Richard Hassing, Studies in Philosophy and the History of Philosophy, 30 (Washington, DC, 1997), 71–82 and the critical review of James G. Lennox, *Aristotle's Philosophy of Biology: Studies in the Origins of Life Science* (Cambridge, 2001), pp. 225–28.

[13] *On Respiration* 3 (471b24–29); Albert, *De spiritu et respiratione* (ed. Borgnet 9:213–55).

[14] See, for example, Anthony Preuss, *Science and Philosophy in Aristotle's Biological Works* (Hildesheim, 1975), p. 251 and Lennox, *Aristotle's Philosophy of Biology*, p. 259.

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science.[15] Given this, one might expect that an Aristotelian understanding of optimal design models and their application to explaining the fitness of organisms remains relevant to understanding the modern adaptationist program in particular and the nature of scientific explanation in general.

2. The Structure of Optimality Models

Among the most prevalent ways of characterizing organic adaptation among Neo-Darwinians is in terms of models that provide insight into the morphological and behavioral design of organisms by describing their fitness as a function of certain design variables. Such models allow the scientific investigator to determine what design-variable values maximize fitness. These fitness-maximizing combinations of values constitute the optimal design of the organism, relative to the demands of living in a certain environment and given the genetic limitations of the organism under study. An example of this kind of modeling is used in the explanation of the predatory behavior of the praying mantis (*Mantis religiosa*).[16] Through a geometrical analysis of prey in the grasp of the mantid foreleg, Canadian biologist Crawford Holling was able to characterize the diameter of the prey fragment as a function of various parameters of foreleg anatomy. On the basis of this analysis, he determined the largest prey fragment that could be locked into the mantid grasp. Holling then reasoned that the capture of prey that approached this maximal size is more energy efficient in terms of the energy expended relative to the energy consumed by the mantis in hunting. This allowed him to characterize the increase of mantid fitness as a function of the increase of energy efficiency. The optimal predatory behavior for the mantis, therefore, is to attack prey of the maximal diameter relative to the mantis' grasping capacity. Observation confirmed that, in fact, mantises most often attack prey of that size.

The distinction between the optimal and the maximal is fundamental to optimality modeling. *Optimality* is a qualitative characterization of a particular organic adaptation understood as one of a number of alternatives. Optimal states cannot be identified only with respect

[15] The recent work of Rom Harré on a realist account of productive causality is an example; see his foundational study *The Principles of Scientific Thinking* (Chicago, 1970). For a comprehensive Neo-Aristotelian account see William A. Wallace, *The Modeling of Nature* (Washington, DC, 1997).

[16] Crawford S. Holling, 'The Analysis of Complex Population Processes', *Canadian Entomologist* 96 (1964), pp. 335–47. For a general treatment of geometrical optimal designs see his 'Cross-Scale Morphology, Geometry, and Dynamics of Ecosystems', *Ecological Monographs* 62 (1992), pp. 447–502.

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to the alternatives, but must have reference to something beyond the possibly optimal alternative. The claim, for example, that a birth weight of seven pounds is optimal for a human infant cannot be made from a definition of the range of all possible birth weights. Reference must be made to something other than possible birth weight to make sense of optimality. *Maximality* (or *minimality*), on the other hand, is the quantitative characterization of morphological or behavioral states based on an internally defined scale. In the range of one to ten pounds of birth weight the maximal is ten. Optimality is not internally defined, but maximality is an internally defined characterization of a metric scale. In optimal design models, optimality is grounded in maximality. A state is optimal among all possible alternatives when it maximizes whatever characterizes optimality. Thus, if the optimal weight for sustainability outside of the womb is seven pounds, then seven pounds is maximal sustainability, six pounds is 85% sustainability, and so on. The optimal weight for the infant, then, is the weight at which its life and growth is maximally sustainable.

The relationship of optimality and maximality can be formally set out in terms of a mapping process.[17] Arguing that some adaptive state S_o is optimal among a set S of alternative states of adaptation $\{S_1, S_2, S_3, \dots\}$ requires a mapping of S onto some other character C that has an associated metric scale $\{\dots, C^{-3}, C^{-2}, C^{-1}, C^{0}, C^{+1}, C^{+2}, C^{+3}, \dots\}$. S_o, then, is optimal because it maps onto C^m the maximal value of C. The task of the biologist constructing an optimality model is to define a maximality scale that provides a criterion for optimality. In adaptation studies, fitness is the optimal state and the morphological or behavioral characteristic that maximizes fitness is optimal for the organism. The range of possible alternative adaptive states is mapped onto the range of measurable morphological characteristics or behaviors in such a way that the maximally fit morphology or behavior determines what characterizes optimal fitness.

In Aristotelian terms, optimal fitness is the final cause of the organism's morphology or behavior and is defined by the maximally fit morphology or behavior relative to living and flourishing in a specified environment. Questions of fitness for the Aristotelian always arise out of a puzzle concerning some observed morphological or behavioral characteristic of an organism. The puzzle is solved by demonstrating that a certain maximally fit morphology or behavior is optimal for the organism with respect to fitness and is observed to be

[17] What follows is a somewhat more formalized version of the summary account of optimal design models given by Richard C. Lewontin, 'The Shape of Optimality', in *The Latest on the Best*, pp. 151–59, especially p. 152. For a more fully worked out example of optimization in population genetics see the appendices to John Beatty's 'Optimal-Design Models and the Strategy of Model Building in Evolutionary Biology', *Philosophy of Science* 47 (1980), pp. 532–61, especially pp. 556–59.

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measurably present in the organism. If the investigator, for example, is able to determine that escape from predators by means of locomotion is optimal for an organism's survival in a particular environment, then that morphology allowing for maximal fleetness or evasion will be optimal. Having established a scale for fleetness or evasion, the optimal fitness of the organism is demonstrated by mapping the set of genetically possible escape alternatives onto the fleetness/evasion scale and articulating the logical connection between the maximally fleet/evasive behavior and the adaptive state that is optimally escapist.

3. Requirements for Optimality Models

While the actual structure of optimality models is not too difficult to grasp and the construction of such models is fairly straight-forward, the prerequisites for optimality model building may be quite complex. There are at least three notable requirements that a biological investigator will have to satisfy, in one way or another. Each of these requirements presents a host of ontological and epistemological difficulties. These difficulties do not make optimality models for adaptation impossible, but they do raise issues that must be considered if one is to avoid a trivial understanding of optimality theory.[18]

First of all, the investigator must determine a criterion scale for the range of possible metrical alternatives in the set *C* of morphological or behavioral variations. In attempting to determine the optimal adaptation of an animal living in an environment containing possible predators and given certain genetic constraints, the investigator will have to determine whether the relevant metrical scale ranges over degrees of fleetness or evasion or some other behavior. As the Aristotelian understanding of natural necessity is of conditional or suppositional necessity, the puzzle prompting an account in terms of optimality models will arise out of observation of the subject's actual behaviors. This will provide at least some preliminary guide to determination of the criterion characteristic. Yet, problems may remain, if observation includes several distinctly measurable behaviors that can be mapped onto a certain range of alternative candidates for optimal benefit. Limitations on the investigator's knowledge of the larger range of goal-directed behavior may also be a factor, as when a certain behavior appears directed toward one end and, upon further study, turns out to be actually directed at another. Thus, even if initial observation provides some direction in the selection of a criterion scale, there remains a need for further definition and ordering of data

[18] The three requirements given here are based on a series of five questions put to optimality theory by Richard Lewontin, 'The Shape of Optimality', p. 152.

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as well as some testing procedure to determine what is relevant to fitness characterized in a certain way.

Second, the topology of the mapping must be determined. Even supposing that the investigator is able to determine a criterion scale *C* in some reliable manner, this alone does not fix the mode of mapping. There may be a one-to-one mapping of the set of alternative adaptive states *S* onto the morphological or behavioral range *C*, but there may be other possibilities. One way in which such a problem arises is with respect to determining the meaning of S_o, the optimal adaptive state, prior to mapping it onto some maximality scale. Harvard biologist Richard Lewontin points out that the bare notion of fitness will not do, for this is ambiguous.[19] Are the alternative states in *S* to range over the mean fitness of a population or the fitness of particular genotypic or phenotypic classes? Concern with one sort of fitness may map the alternatives in *S* onto the criterion scale *C* in a different manner than does fitness taken in another way. Now, this is not necessarily a problem if one can collapse the mean fitness of the population with the fitness of the type. Yet, if the species is polymorphic for characters, as many species are, then the problem remains. The optimal escape from predators of the herd understood as average herd fitness may map onto the criterion scale of fleetness so that the optimally adaptive behavior is that which maximizes herd fleetness. Yet, if the species is also capable of avoiding areas or times of likely predation, this will complicate the mapping procedure.

Finally, the investigator will need to determine the range of the set of alternative adaptive states *S* to which the mapping will apply. The range of possible adaptations is determined, in part, by genetic constraints. Yet, such an ontological limitation cannot be the only factor considered. There remains an epistemological issue, for as Aristotelians will be quick to point out, optimal designs function as causal explanations of fitness. This demands that optimality arguments must map potential states of adaptation onto a measurable criterion that is already determined to be causally relevant to the fitness in question. Richard Lewontin points out that optimality models will always characterize fitness in some measurable terms, such as energy expenditure, growth rate, territory size, feeding efficiency, and so on. This is necessary for such quantifiable states are to be shown by the model to stand in some simple relationship with the unmeasurable quality fitness, namely, the relationship articulated by the mapping. If the model is to be useful in the explanation of fitness, then it must map adaptive states onto a measurable criterion that is known to be a cause of the fitness. Degrees of fleetness provide measurable criteria onto which optimal escape from preditors can be

[19] Lewontin, 'The Shape of Optimality', p. 153.

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mapped in such a way that the maximal fleetness can be shown to be the cause of the escape from preditors that characterizes fitness. Without the determination that escape is the causally relevant factor to be mapped onto the range of fleetness quantities, the investigator is left with an empty definition of fitness as the maximally fleet.

4. Optimality Models and Aristotelian Scientific Method

The long history of the development of scientific method in the Aristotelian tradition constitutes an account of continuing refinements that eventually gave rise to many of the research and testing techniques currently in use among biologists. While this history has not been one of unbroken progress, scholarship reveals a definite progression.[20] Aristotle himself held the goal of scientific research to be knowledge of the natural subject in terms of its productive causes and he described a two-staged dialectical methodology of discovery and demonstration as the means by which knowledge of natural causes comes to be possessed.[21] Medieval and early modern Aristotelians refined the methodology and put it into its canonical form which was employed by Galileo, Harvey, and other early modern researchers.[22] Among the refinements added during this period was an intermediate stage of testing interposed between the two stages of Aristotle's original method. Contemporary Neo-Aristotelians argue for the continuing relevance of the methodology,[23] especially in its canonical form, to the general articulation of the structure of scientific research. It is in this methodological context, therefore, that optimality models will

[20] While much historical scholarship has been done on the development of Aristotelian method, the most complete philosophical history remains William A. Wallace, *Causality and Scientific Explanation* (Ann Arbor, 1972). See also the studies in James A. Weisheipl, *Nature and Motion in the Middle Ages*, ed. William E. Carroll (Washington, DC, 1985).

[21] Among the best recent studies of Aristotle's method as a dual-staged procedure is that of Michael Ferejohn, *The Origins of Aristotelian Science* (New Haven, 1991). For the application of this method to biology see the various studies in *Philosophical Issues in Aristotle's Biology*, ed. Allan Gotthelf and James G. Lennox (Cambridge, 1987) and Lennox, *Aristotle's Philosophy of Biology*, especially 1–125.

[22] For the medieval application to biological research see my 'Albert the Great and the Revival of Aristotle's Zoological Research Program', pp. 30–68. On the early modern developments see William A. Wallace, 'Galileo's Regressive Methodology: Its Prelude and Its Sequel', in *Method and Order in Renaissance Philosophy of Nature: The Aristotle Commentary Tradition*, ed. Daniel A. DiLiscia, Eckhard Kessler, and Charlotte Methuen (Aldershot, 1997), pp. 229–52; see also Wallace's *Galileo's Logic of Discovery and Proof: The Background, Content, and Use of His Appropriated Treatises on Aristotle's Posterior Analytics*, Boston Studies in the Philosophy of Science, vol. 137 (Dordrecht, 1992) and 'William Harvey: Modern or Ancient Scientist?' in *The Dignity of Science: Studies in the Philosophy of Science*, ed. James A. Weisheipl (Washington, DC, 1961), pp. 175–208.

[23] See, for example, William A. Wallace, 'The Intelligibility of Nature: A Neo-Aristotelian View', *Review of Metaphysics* 38 (1984), pp. 33–56.

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be discussed here in an attempt to designate with some precision the place of such models in a traditionally realist approach to scientific explanation.

In his description of the demonstrative method of causal explanation, Aristotle had distinguished between those demonstrations that establish the existence of the facts about the subject under study and those that provide the reasons for these facts. This distinction provided the basis for the three stages of reasoning underlying all research programs according to a Neo-Aristotelian philosophy of science. The first stage, the discovery phase, essentially reasons from effect to cause while the final or explanatory phase reverses or regresses the reasoning, moving from cause to effect. Given that the observed effect is initially better known than its underlying cause, every research program begins with the process of establishing what is true of the subject as the effect of some yet unknown cause. The goal of the research program is eventually to attain enough knowledge of the subject considered as an effect such that possible candidates for explanatory cause are suggested. These candidates for explanation are sifted, tested, and eliminated or confirmed in the intermediate stage or testing phase of research. The goal here is to narrow down the field of candidates for causal explanation and eventually to select one that is convertible with the effect. This intermediate stage is often the most difficult and time-consuming, for significant and repeated testing, experimentation, or computation may be required to select rigorously from among those candidates for explanation that have emerged from the initial discovery phase of research wherein the subject was first encountered, observed, and measured. Actual explanation is achieved in the final phase when the cause that has emerged from the testing procedure is rigorously demonstrated to be convertible with the effect and the investigator formally grasps it as precisely that unique cause required to produce the observed effect. At the end of the process of scientific research, then, what was initially more familiar to the investigator in his experience is now understood as the product of a cause that accounts for the existence, form, and function of the effect under study.

To set out scientific method in terms of stages or phases like this is not, of course, to claim that every research program is divided into temporal stages that must be completed separately. Often one stage overlaps another in the investigator's actual activities. Also, previous research on the subject in question or on similar subjects may constitute all or part of some stage and may be imported by the investigator into his own research program. Rather, the methodological stages represent the logical structure of scientific reasoning in a way that shows what is essential to any research program. While the phases of this reasoning process may overlap with other phases or even with other research programs, they do constitute distinct forms

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of reasoning that stand in a certain epistemological order. Both the distinction of stages and the order of their epistemic dependence can be summarized and applied to biological adaptation studies as follows.

The Discovery Phase. In biology, as in all natural sciences, research always begins with the inventive or discovery stage which, as has been said, possesses the general structure of a reasoning from observed effect to explanatory cause. This stage of research is the most complex in terms of the variety of techniques employed. This is because it not only involves the initial encounter of the investigator with the organism in observation and measurment, but also involves a broad range of methods by which the organism and its adaptation are progressively defined. This may involve complex isolation or observational techniques, experimentation of various kinds, types of taxonomic ordering, inductions to various natural regularities, and so on. At this stage of investigation, the adaptive cause of the observed morphology or behavior is suspected or proposed, but the causal formality that constitutes the true explanation is not yet fully recognized. Often investigators will presume the adaptation to be constituted in a certain manner as a way of allowing research to continue in a certain direction that is suspected eventually to yield the adaptive cause in a more formal way. Such preliminary candidates for adaptive explanation often must be modified or even abandoned and replaced as the morphological or behavioral facts about the organism become progressively better know.[24] Through all of these means, the investigator both attains data for study and organizes them in a manner that has the best chance of demonstrating the connection between the adaptation of the organism and its observed morphology or behavior.

The Testing Phase. The intermediate or testing stage is necessary because the initial encounter with the organic morphology or behavior, considered as an effect of some not yet fully understood adaptive cause, must eventually be shown to be convertible with its adaptive state. Yet, the various techniques of scientific discovery are not necessarily sufficient to demonstrate the existence of the morphology or behavior in a way that formally connects the suspected adaptive state with the observed characteristics of the organism. Often experimentation is necessary to test the suggested explanations arising out of the empirical investigations of the discovery stage and extensive computation may be necessary to fully delineate the parameters of the morphology or behavior relevant to its adaptation. Most importantly, given a not yet formally known but suspected adaptive cause,

[24] Albert and Thomas recognized the importance of such *enunciationes ut nunc* in research programs. For references see John A. Oesterle, “The Significance of the Universal *Ut Nunc*’, *The Thomist* 24 (1961), pp. 163–74.

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other possible adaptations must be eliminated before the suspected adaptation can be known as convertible with the morphological or behavioral effect and, thereby, established as the unique cause of that particular effect.

The Explanatory Phase. Once the subject of research has been properly isolated and defined and the various possible candidates for formal adaptive explanation have been narrowed down to one, the connection between adaptation and morphology or behavior can be demonstrated as necessary. The explanatory stage of research is achieved when the adaptation is known by the investigator as ontologically prior to the morphology or behavior and known precisely as the reason why the morphology or behavior is present in the organism. The observed morphology or behavior, initially better known than the adaptive reason for its existence, is now seen to be convertible with the fitness of the organism for surviving and flourishing in its environment and given its genetic limitations.

Optimality models enter into this Aristotelian model of adaptation studies in two ways. First, they provide a means by which a precise description of the adaptive effect under study can be articulated. In this way they are part of the discovery phase of research, for they empirically ground the investigator's work by linking it to the observed fitness of the subject. Observation of the morphology or behavior of the organism in particular respects that raises questions of explanation, requires a means by which the data about the organism can be organized and selected. Not everything observed of the subject will be relevant to the fitness question at hand and some systematic means is needed by which the proper characters can be isolated and defined. A proposed optimal design provides a rigorous and measurable way to do this. Second, optimality models provide the proposed explanation for the adaptive effect to be considered and demonstrated in the explanatory phase. Once the morphological or behavioral model is constructed, tested, and refined, it should be convertible with the fitness of the organism defined with respect to existing and functioning in the environment that originally posed the problem to be solved by the organism for the sake of its survival and flourishing.

Using the Holling Model of mantid predatory behavior as an example, a description of the use of optimality models in research can be set out in Aristotelian terms. The mantis is observed to be predatory and to possess a tendency to attack prey roughly within a certain range of size. Moreover, initial observation indicates certain limits on prey selection. Thus, the question arises whether the observed predatory behavior is an adaptation and, if so, on precisely what terms. On the supposition that the behavior is an adaptation and that mantid behavior is about as effective as possible given genetic and other known limitations, a precise description of the behavior is developed

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as an optimality model. As the model is being so developed, the investigator will select and define the respects in which the behavior will be studied, for example, with respect to energy efficiency. At this stage, the optimality model not only provides empirical description in measurable terms, but also refines the problem by pointing to the relevant factors and the way in which they can be quantitatively stated.

Having selected the relevant morphological and behavioral factors and defined them precisely, the size of prey is determined within the parameters of the model. The size of prey diameter is calculated and an energy efficiency ratio is developed in light of the results of the calculation. The correlation with fitness in terms of energy expended to energy consumed is stated with precision using the terms of the model. The developed model with its empirical referents is then tested by observation. At this stage, the investigator's observations are more directed and quantitatively rigorous than the initial empirical encounter with the subject that raised the fitness question in the first place. This is possible because the model has been refined to the point that its terms are available to guide and focus observation in a way that is more precisely aimed at the particular fitness issue in question. In the testing phase, then, the model of mantid behavior relative to prey size is then confirmed as a useful model of fitness and the fitness, understood as an energy-efficiency benefit, is seen to be a candidate for the explanation of mantid prey selection.

So far the development of the optimality model of mantid behavior has discovered or brought into a precise description the facts relevant to fitness and has confirmed them through reliable observational tests. All of this has been to consider mantid behavior as an effect of the cause of adaptation for the defined environmental demands on the organism. This puts the investigator into a position to recognize the ontological priority of the adaptation for the behavior. The investigator is also in a position to state the modeled adaptation as the cause of the behavior: the mantis tends to attack prey of a certain diameter on account of the maximal energy efficiency of this predatory behavior in that environment. Moreover, the optimal behavior is recognized as convertible with the maximal energy efficiency. In the explanatory phase, then, the optimality model articulates the cause of the adaptive mantid behavior precisely in terms of mantid fitness.

The satisfaction of optimal design requirements as specifically applied to the Holling model can also be put in terms of Aristotelian research methodology. The selection of a criterion scale, in this case, range of prey diameters that can be accommodated by the morphology of the mantid foreleg, is established in the discovery phase. The scale is also set out in such a way that minimal and maximal values are precisely determined for the characteristics in question. This arises out of initial observations and measurements and is refined

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through successive studies of observed mantid morphology and behavior. The mode of mapping alternative mantid predatory behaviors onto the prey-size scale is also determined in the discovery phase of research. This is guided by the parameters of the fitness problem that initiates the research program, in this case, the demands of energy efficiency. As both energy expenditure and energy consumption occurs at the ontological level of the individual mantis, the mean efficiency of the species is not directly relevant. Thus, the available alternatives understood in terms of individual mantid behavior are mapped onto the range of prey sizes available to the individual. Also, in the case of mantid predation, polymorphism is recognized as irrelevant, for energy consumption is a factor of prey size and not of other factors. While the range of alternative adaptive states is initially set out in the discovery phase of research, it may be necessary to refine it with respect to the requirements of causal explanation in the testing phase. In the case of the mantis, the set of alternatives in terms of energy expenditure becomes defined by observation and measurement relative to the observed availability of prey in the environment during the discovery phase. The final determination of causal relevance, however, comes only in the explanatory phase when the optimal energy expenditure from among the alternatives has been exactly matched through the mapping process with predation of the maximal prey size and this is recognized as an adaptation. Had not the predatory behavior been first studied as an effect of adaptation, the relevant factors necessary for this recognition would not have come to light.

5. Teleology and Contemporary Biological Research

It is quite obvious that optimal design models in contemporary adaptation studies possess explanatory power precisely insofar as they unify all the causal factors of the observed organic form or behavior in a final cause. The very concept of optimality is inescapably teleological. Moreover, the analysis of optimal design explanations in terms of an Aristotelian conception of scientific method confirms the central role of finality in such explanations. Given this, why have many modern biologists so adamantly rejected the notion of final cause as unscientific? There is much to be said in response to this question that would take us far beyond the limits of the present study. Attention can be focused, however, on what is for many an crucial issue. In the course of the twentieth century, research in biochemistry has significantly deepened understanding of the material constitution of organisms. This has resulted in a predisposition favoring reductionism in biological explanation. Indeed, some see such reductionism as the very essence of scientific method. E. O. Wilson, for example, famously claimed that “reduction is the traditional

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instrument of scientific analysis."[25] On this view, final causes do not actually exist in nature and any explanatory model that makes references to finality is merely a shorthand way of speaking of the material and mechanical causes that do exist in organic nature. Optimal design explanations, therefore, are reducible to explanations in terms of biochemical structures and interactions.

Reductionists admit the utility of optimality models in explaining the adaptation of organisms, but they point out that these models are used on the presumption of the explanative sufficiency of the underlying genetic variation and causal efficacy of natural selection. Data regarding such underlying mechanisms is difficult to attain in practice. Reference to optimal states as final causes allows direct arguments about adaptation without the necessity of knowing what is happening at the genetic and developmental level. For the reductionist, then, optimal design explanations are simply heuristic arguments that stand in place of direct mechanical and material explanations of organic fitness. There are, then, no real final causes in nature and such teleological references are merely a practical expedient. This practical expedient may be always and everywhere necessary for research to proceed, because the direct measurement of the fitness found in the various genotypes is beyond the reach of even the most ambitious adaptationist programs. It remains, nonetheless, a merely practical procedure. There simply is no other explanatory strategy available to make research programs work.[26] Nonetheless, optimal design models are employed on the understanding that they are standing in for more basic biochemical explanations that make no references to final causes.[27]

In response to this kind of reductionism modern Neo-Aristotelians have several things to say. First of all, they will point out that the prior commitment to reductionism necessary for this heuristic interpretation of optimal design models must be justified independently of such models and of adaptationism generally. If adaptation must, practically speaking, be expressed in terms of optimality, then it is not clear just what such justification would be based upon. If the only way open to us in speaking of the reality of organic fitness is in terms of final causes, then how does one justify the claim that finality is not real,

[25] 'On Human Nature', reprinted in *The Study of Human Nature*, ed. Leslie Stevenson (New York: Oxford University Press, 2000), p. 275.

[26] See the remarks on this point by Richard Lewontin, "The Shape of Optimality', especially p. 151.

[27] Recent philosophers of science disagree on whether biological reductionism is a reduction of teleological explanation to non-teleological explanation or of biology to chemistry. See the classic discussion of Ernest Nagel, *The Structure of Science* (New York, 1961), pp. 398–446 and the response of Charles Taylor, *The Explanation of Behaviour* (London, 1964), especially ch. 1. For the position of Aristotle in respect to this debate see Gotthelf, 'Aristotle's Conception of Final Causality', p. 208, n. 10.

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but only a necessary way of speaking? Were reductionism true, then how could one consider optimal design models as explanations of the real adaptation of actual organisms? Second, Neo-Aristotelians will point out that reductionism has not been philosophically justified, but simply presumed in the course of the history of science. That early modern natural philosophers abandoned final cause explanation in favor of a mechanistic worldview is hardly, by itself, justification for that reductionist worldview.[28] Finally, Neo-Aristotelians will point out that the kind of explanation found in optimality modeling relies on a conception of causation that requires an ontology quite different from the mechanistic worldview that historically was the genesis of modern reductionism. Once that worldview is abandoned, there is no need to restrict causation to that sort of mechanical interaction which caused David Hume and his followers to reject the reality of *any* kind of causation, let alone final cause. On the Aristotelian view, the purpose of scientific research is to disclose the real causes underlying observed phenomena. Thus, if optimality models are truly explanative, then the finality they disclose to the scientific investigator is actual and not simply a mode of speech.[29]

Yet Aristotle, especially as interpreted by Albert and Thomas, held that the biological investigator must account for the development of organisms in terms of their constituent materials and material interactions.[30] This suggests that an Aristotelian understanding of optimal design, while requiring a realist ontology that includes final causes, remains rooted in material and agent causes. Albert especially insisted that it is a mistake to interpret Aristotle as holding that organisms are anything other than basically material in nature. The form of organisms and the natural agencies that produce those forms can only be understood in relation to the material constitution of organisms. At the same time, the form of an organism cannot be reduced to its matter and the final optimal state of the organism cannot be reduced to the natural processes that bring it about. Organic morphology remains irreducibly formal while existing only in matter. Natural processes remain irreducibly teleological while remaining material processes. Aristotelians, then, agree with modern biologists on the importance of the underlying materials and mechanisms of

[28] On this point see Robert Sokolowski, 'Formal and Material Causality in Science', *American Catholic Philosophical Quarterly* 69 (1995), pp. 57–67.

[29] For further discussion, see Benedict M. Ashley, *The Way toward Wisdom* (Notre Dame, 2006), pp. 343–46. See also Etienne Gilson, *From Aristotle to Darwin and Back Again: A Journey in Final Causality, Species, and Evolution*, tr. John Lyon (Notre Dame: University of Notre Dame Press, 1984).

[30] For references in Aristotle, see Gotthelf, 'Aristotle's Conception of Final Cause', 204–42, especially pp. 208, n. 9 and pp. 234–37. See also the remarks of Albert in his *De animalibus* XI, tr. 2, c. 4 (tr. Kitchell and Resnick, pp. 892–93).

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organisms without at the same time accepting the reduction of the organism's reality to its material and biochemical mechanisms.

This brings us back to the question: if Aristotelian explanation in terms of final cause is so naturalistic, then why do many modern biologists reject the necessity of final cause in biological explanation, except as a mere heuristic? Perhaps the Aristotelian notion of final cause is widely misunderstood and confused with other teleological ideas that may remain scientifically problematic where actual Aristotelian teleology is not. This, in fact, is the judgment of the late Harvard biologist Ernst Mayr. He sharply distinguished the teleology of eighteenth-century natural theologians from various end-oriented natural phenomena. The former sort of theological teleology understood natural change as being due to an inner force or tendency toward progress. Organisms naturally tend toward greater and greater perfection as part of an overall cosmic orientation toward some, perhaps divine, final end. This, Professor Mayr argues, is quite different from the claim that natural change is directed toward an end or that nature acts for the sake of something. He finds teleology in the theologically progressive sense to be an unscientific idea whereas he fully accepts the reality of end-orientation in nature.[31]

Professor Mayr perfers to call the notion that nature has an inner tendency toward cosmic perfection "teleology" in the strict sense. This he distinguishes from two other kinds of "tending" toward an end. There are in nature what he calls "teleomatic ends." These are simply the ends toward which any natural change or process is directed as determined by the natural properties of the subject of change. All inorganic change is like this and is defined in terms of ends understood in this teleomatic way. Thus, a river is a teleomatic process because it flows in a certain direction — say, toward the sea — the end being its emptying into the sea. Radioactive decay is a teleomatic process and, for each element, proceeds in the same way wherever that element is found. Such orientation to a natural end is not, he claims, truly teleological, for there is nothing purposeful in teleomatic processes, if one means by "purpose" a conscious intention.[32]

Teleomatic processes can be distinguished from what Professor Mayr prefers to call "teleonomic" processes. Teleonomy involves true goal-directedness in nature. It is when natural change proceeds according to a "program" in which the goal is in some sense "foreseen" in the process from the beginning. Organic processes, such as growth and cellular processes, are teleonomic as are organic behaviors

[31] Ernst Mayr, *Toward a New Philosophy of Biology* (Cambridge: Harvard University Press, 1988), pp. 234–36; see also his 'The Idea of Teleology', *Journal of the History of Ideas* 53 (1992), pp. 117–35, especially pp. 118–19 and pp. 133–35.

[32] Mayr, 'The Idea of Teleology', pp. 125–26.

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such as feeding, migration, and reproductive behaviors. What distinguishes a natural process as teleonomic as opposed to merely teleomatic is that teleonomic changes proceed according to prearranged information that controls the process orientating it to its goal. As Professor Mayr puts it, a teleonomic process is not simply a description of an end-oriented process, "but a set of instructions" for how the process is to proceed toward its end. This is what makes it truly goal-oriented and not simply a tendency to an end.[33]

On Mayr's view, then, optimal design models are teleonomic models providing explanation of programmed goal-oriented organic processes in terms of morphological or behavioral goals. He points out that such explanation is quite different from teleological explanations of the theologically progressive sort. Teleonomic processes involve proximate causes, exist as material processes, and unfold according to a program that is fully describable in naturalistic terms. They constitute the scientific explanation of the organism without the necessity of invoking extra-natural processes or entities such as divine intention or some irreducible "inner" force within nature.

Professor Mayr's distinction between the teleomatic and the teleonomic is precisely what one finds in the Aristotelian tradition. Aristotle himself distinguished between that which happens in nature "by necessity" and that which is "for the sake of something."[34] Natural processes that occur "by necessity" are those that occur "always or for the most part" and correspond to Mayr's teleomatic processes. Those that are "for the sake of" the production of some organic morphology or behavior and are optimally beneficial to the organism correspond to Mayr's teleonomic processes.[35] Thomas explains:

> It should be said that every agent necessarily acts for an end. When one cause is ordered to another, the removal of the primary cause necessitates the removal of the others. Primary among all causes is the final cause. The reason for this is that, material does not result in a form unless it is caused by an agent to be so formed, for no potentiality can cause itself to become actual. An agent, however, cannot cause this except by aiming to achieve it as an end. If the agent were not oriented to producing a particular effect, then it would not produce this effect

[33] Mayr, 'The Idea of Teleology', pp. 126–30. For his general account of teleonomy see 'Teleological and Teleonomic: A New Analysis', *Boston Studies in the Philosophy of Science*, 14 (1974), pp. 91–117.

[34] Aristotle uses the terms *ex anangke* and *to hou heneka* at *Physics* II, 5 (196b21) to distinguish natural regularities from what happens in order that a certain form come to exist.

[35] *Physics* II, 5 (196b18); Thomas, *Commentaria in Physicorum Aristotelis* II, lect. 8 [212] (ed. Marietti, p. 105).

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> rather than that effect. In order to produce a particular effect, the agent must be determined to that particular effect which defines its end.[36]

The explanation of the adapted organism will always be in terms of its material and agent causes. Yet this organism cannot exist in nature as the well-adapted organism it is on account of its material components and the mechanisms operating on the material alone. This is because the material in itself is only potentially this adapted organism, and the mechanism operating on it is in itself only a natural motion. The adaptation can only be explained when the material potentiality is understood in light of the optimal state constituting the adaptation, and the mechanism that actualized this material potentiality is understood as actualizing *this* optimally adapted organic state. Thomas' point is not only that a final cause is necessary for the end result, but also that a final cause cannot be reduced to material and agent causes. Without an account of the final cause, the optimally-fit state of the organism, one could not even begin to formulate an account of the organism's material and agent causes as the causes of its fitness. There is no "inner force" at work in organisms, on this Aristotelian view, nor is it necessary to introduce a cosmic progression to explain the adaptation of organisms. There is only the necessity of understanding all the causal factors of organic adaptation in terms of a programmed goal-orientation.

6. Conclusion

Optimality models remain the most widely used means by which organic adaptation is understood. Partly this is due to the evocative character of such engineering models in their role of providing a picture of nature's operations. It is also due to the power these models possess to bring the various morphological, behavioral, genetic, and environmental facts about organisms together into a comprehensive explanatory narrative. With their potential for both iconic and quantitative treatment of adaptation, optimality models are among the most powerful research strategies available to account for organic development.

[36] "Dicendum quod omnia agentia necesse est agere propter finem. Causarum enim ad invicem ordinatarum, si prima subtrahatur, necesse est alias subtrahi. Prima autem inter omnes causas est causa finalis. Cuius ratio est, quia materia non consequitur formam nisi secundum quod movetur ab agente: nihil enim reducit se de potentia in actum. Agens autem non movet nisi ex intentione finis. Si enim agens non esset determinatum ad aliquem effectum, non magis ageret hoc quam illud: ad hoc ergo quod determinatum effectum producat, necesse est quod determinetur ad aliquid certum, quod habet rationem finis." *Summa theologica* I-II, q. 1, a. 2, co.

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From an Aristotelian point of view, the prevalence of optimality models in biological explanation provides a good example of the role played by teleology in research programs. Moreover, such models are not merely heuristic accounts standing in for a detailed knowledge of the developmental processes and actual genetic variation of organic characteristics. Final causes, in their role of unifying the material and mechanical causes of organisms into a comprehensive explanatory account, cannot be reduced to the causes they unify. This is because material and agent causes by themselves cannot function as a unified explanation of organic adaptation. Were they able to do so, optimality arguments would not be necessary. Indeed, they would not even be meaningful.

Correctly understanding the Aristotelian notion of final cause places no barrier to naturalistic explanation of organisms. The sort of teleological explanation used by medieval Aristotelians such as Albert and Thomas does not rely on the importation of non-naturalistic causes into nature. The autonomy and integrity of natural science remains unimpaired by Aristotelian final causes. Indeed, final causes, rightly understood, confirm the fruitfulness of scientific research, for they imply that the divine source of the natural order studied by the natural sciences is a completely other matter and is the subject of an altogether different science. Those who today are confused or concerned by the debates over the theological implications of contemporary biological research would do well to attend to the careful and rigorous conception final cause found in the works of such thinkers as Albert the Great and his student Thomas Aquinas.

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