Chapter 8
Adopting a Technological Stance Toward the Living World. Promises, Pitfalls and Perils

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Abstract In this essay, I explore the theoretical, methodological and ethical dimensions of adopting a technological stance toward the natural living world. In Part 1, I discuss the importance of adaptive match as a central explanandum of biology, offer a tentative definition of "biological design," and argue that inferences of intentional design in nature often flow from rational deliberative faculties, rather than solely or even primarily from cognitive biases toward teleological explanation or culturally inculcated religious beliefs. In Part 2, I examine the virtues of technological thinking in biology that flow from important structural similarities between organisms and artifacts, which permit the testing of evolutionary hypotheses and reveal the physical constraints on evolved design. This analysis is balanced in Part 3 by an investigation of the pitfalls associated with technologic thinking in biology and in popular science education, where I discuss a range of problems that arise from thinking of organisms as machines and describing their features in artifactual terms. Finally, in Part 4, I consider ethical misgivings about embracing the technological stance, such as the worry that an 'instrumentalist' attitude toward nature could lead to the mistreatment of beings with moral status, or that the design of organisms for human purposes expresses disrespect for living things or a pernicious desire for mastery over nature.

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1 Introduction

Despite the astounding success of modern evolutionary theory in explaining the origins and persistence of functional complexity in nature, design thinking remains ubiquitous in biological science, education and science journalism. Organisms are frequently described and investigated as if they were rationally designed artifacts. Ecological engineering analyses play critical roles in assessing the functionality of structures, testing adaptive hypotheses, and understanding the biomechanical constraints that underwrite convergent evolution in distant lineages. Without recourse to technological thinking, it is difficult to make sense of organismic features, strategic evolutionary interactions, and the adaptive match between organism and environment. Creative biological sciences, such as synthetic biology, aim to use engineering principles to design living artifacts that are exquisitely tailored to human purposes, causing further conceptual enmeshing of evolved organism and engineered artifact. Why does technological thinking continue to feature so prominently in biological science and communication despite the profound etiological and synchronic dissimilarities between organisms and artifacts? Is this an unfortunate legacy of pre-Darwinian theories of nature that should be eliminated from or relegated to the margins of scientific discourse? Or is it a defensible, perhaps even indispensable, component of biological research and education?

In this chapter, I explore the theoretical, methodological and ethical dimensions of adopting what I will call a *technological stance* toward the natural living world. My aim is to sketch a comprehensive, accessible, and overarching view of the philosophical landscape, rather than to investigate any particular dimension in great detail. In **Part 1**, I discuss the importance of adaptive match as a central biological explanandum, offer a tentative definition of "biological design," and argue that inferences of intentional design in nature often flow from rational deliberative faculties, rather than solely or even primarily from cognitive biases toward teleological explanation or culturally inculcated religious beliefs. In **Part 2**, I examine the virtues of technological thinking in biology, which, I argue, stem from important structural similarities between organisms and artifacts that are inferentially rich, permit the testing of evolutionary hypotheses, and reveal the physical constraints on evolved design. This sanguine analysis is balanced in **Part 3** by an investigation of the pitfalls associated with technological thinking in biology and in popular science education. Here I discuss a range of problems that arise from thinking of organisms as machines and describing their features in artifactual terms. Finally, in **Part 4**, I consider ethical misgivings about embracing the technological stance, such as the worry that an 'instrumentalist' attitude toward nature could lead to the mistreatment of beings with moral status, or that the design of organisms for human purposes expresses disrespect for living things or a pernicious desire for mastery over nature.

2 Part 1: The Conceptual and Theoretical Foundations of Biological Design

2.1 That Mystery of Mysteries

Immanuel Kant (1790) famously proclaimed that there would never be a Newton for the blade of grass.[1] Kant was skeptical not only of our ability to explain the spontaneous origin of living things from inanimate matter, but also of the possibility of explaining the origins of 'natural ends' without recourse to an intelligent designer (1790/2007, 228). Many authors have been quick to tout Charles Darwin as precisely such a 'Newton,' insofar as Darwin offered the first and only naturalistic solution to what the philosopher Sir John Herschel called "that mystery of mysteries"—the origin and extinction of species. In fact, it is not clear that Darwin solved Herschel's mystery, since the role of natural selection in speciation and extinction remain contested. Darwin did, however, solve another, perhaps even more profound, biological mystery, which we might call "that Mystery of Mysteries" (in caps): Namely, the exquisite match between the traits of organisms and the ecological design problems that they need to solve.

Darwin's theory of natural selection offered an elegant mechanistic explanation of the natural adapting of means to ends that Kant claimed was in principle unsolvable. Accounting for the non-accidental pairing between the traits of organisms and their particular lifeways is one of the singular crowning achievements of evolutionary biology (Ayala 2007), unifying a staggeringly diverse set of observations under a single schema (Kitcher 1985; Brandon 1990). But Darwin was not simply another 'Newton.' Whereas Newtonian physics has been superseded by relativity theory, Darwin's postulated combination of blind variation and natural selection remains to this day the only viable explanation for the origins and maintenance of adaptive match, functional complexity, and teleological behavior in nature.

Some adaptive matches can plausibly be explained as simple coincidence. Once, while hunting for fossil shark teeth in the hilly phosphate mines of Aurora, North Carolina, I came across a small population of pale gray-colored grasshoppers that were a spot-on match for the chalky excavated substrate, providing a near-perfect camouflage from birds. Thinking that I had discovered a case of 'industrial albinism' (adaptive lightening to human-altered environments), I snatched up one of the grasshoppers and brought it back to an entomologist at Duke University, where I was completing my doctoral work at the time. As it turned out, to my surprise, the Aurora mine grasshoppers were actually invaders from a remote coastal population. As luck would have it, they blended near-perfectly into the excavated substrate.

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[1] The quote from Kant's *Critique of Judgment* (1790/2007, 228) reads as follows: "we may confidently assert that it is absurd for human beings even to entertain any... hope that maybe another Newton may some day arise, to make intelligible to us even the genesis of but a blade of grass from natural laws that no design has ordered. Such insight we must absolutely deny to mankind."

In contrast to such ‘single-dimension’ organism-environment pairings, traits that have been molded along multiple dimensions to solve a complex adaptive problem cannot plausibly be explained away as a fluke. Following Allen and Bekoff (1995) and Lewens (2004), I will use the phrase “biological design” to describe any product of cumulative selection that has been ‘shaped’ or ‘molded’ along multiple, coordinated dimensions to produce a complex function or adaptive match—an outcome that, in paradigmatic cases, is astronomically unlikely to have arisen through pure chance or stochastic processes alone.

For example, some species of butterfly in their larval (caterpillar) state mimic snakes in order to discourage predation by insectivorous birds. One such butterfly, the spicebush swallowtail (*Papilio troilus*), boasts a suite of morphological and behavioral modifications that result in an uncanny resemblance to the common green snake. This includes a thorax in the shape of a snake’s head featuring two large snake-like eyes, a red retractable ‘forked tongue’ (which is actually a pheromone-emitting organ), and a rearing/striking behavior that mimics the aggressive posturing of snakes.[2]

All biological designs are functional in the sense that they proliferated in a population due to their fitness-enhancing effects (see Sect. 2.2). However, not all functional traits rise to the level of biological designs. Some traits originate from a single mutation and are swept to fixation by selection without being shaped along multiple, developmentally independent, dimensions. For instance, if the extant white polar bear coat originated in a single mutation that was driven to fixation by selection, it would not constitute “biological design” on the definition given above despite having evolved to solve a straightforward ecological *design problem*—namely, avoiding visual detection against a pale substrate. Hence, neither selection nor adaptive match is sufficient for biological design.[3] Furthermore, as in the realm of artifacts, not all configurations that are properly referred to as “designs” will be functional in the sense of constituting a straightforward adaptive match. Some sexually selected traits, such as ornamental features like the peacock’s elaborate tail or the lizard’s dewlap, constitute *adaptive mismatch by design*—these are thought to be selectively shaped predation ‘handicaps’ that send hard-to-fake signals of vitality to prospective mates.

It is best to think of biological design as a continuum: the greater the number of developmentally independent parameters of a trait that are shaped through cumulative selection, the more that trait will tend to resemble paradigmatic cases

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[2] Creationists have been keen to point to putative ‘irreducibly complex’ traits in which a change to any trait parameter would allegedly vitiate the functionality of the trait. But most biological designs are not delicate in this respect. The spicebush swallowtail morphology, for instance, would still have bird-averting properties even if it lacked the retractable forked ‘tongue’.

[3] Note, however, that selective ‘shaping’ should not be construed solely in topological terms—it only requires selection for a trait with multiple, independently modifiable parameters that can be represented in a phase space. If the evolution of polar bear coats involved selection along multiple, developmentally independent parameters, then it would constitute an instance of biological design.

of biological design, such as the vertebrate eye. Interestingly, the same holds true for artifacts: the more that features of an object work together in coordinated fashion to produce a specialized utility (or aesthetic outcome), the clearer that object is one of design. A simple flake struck from a rock core is far less obviously a case of design than is a samurai sword.

2.2 Design Without a Designer

In ordinary language, something's being designed implies that it has a designer. The concept of 'design' is thus infused with intentionality, planning and purpose. In contrast, what I have been calling "biological design" is the product of blind variation and natural selection.[4] Yet, Darwin's enduring mechanistic solution to the problem of adaptive match did little to banish design concepts and other teleofunctional language from biology. Unlike the physical and chemical sciences, biology remains entrenched in what Dennett (1995) has called a "design stance" toward the natural living world. Consequently, some have read Darwinian theory not so much as exorcizing teleology from biology, but rather as vindicating it by providing a theoretically sound foundation for the explanatory role of functions in biology.

The long-standing puzzle surrounding biological function was this: How could the function of a trait explain that trait's existence, when the laws of physics require—*contra* Aristotle—that causes precede their effects? The Darwinian solution to this puzzle was to say that function talk is simply shorthand for a causal-etiological claim about the history of selection for some effect. So, for example, to say that the function of the vertebrate heart is to circulate blood is to say that the vertebrate heart exists in its present form and at its present frequency because its tendency to circulate blood had fitness-enhancing effects on ancestors that possessed hearts (Neander 1991). One great virtue of an account of function that is indexed to a history of selection for effects is that it renders biological functions explanatory without violating physical law and without adverting to purposes or intentions.

Importantly, our ability to detect or intuit biological design does not depend on our ability to detect or intuit histories of selection. We identify biological design qua explanandum irrespective of the explanation that it is ultimately afforded. Moreover, we are quite capable of recognizing a biological structure as one of design without understanding its specific function. For instance, we may know that the bony plates on the back of the dinosaur *Stegosaurus* were selected to serve some function, but

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[4] Dawkins (1997) suggests that we refer to natural objects of apparent design as "designoids," in order to distinguish these from genuine objects of design like artifacts. Similarly, Ruse (2004, 265) suggests that at the very least, we should refer to biological design as "seemingly organized complexity." In this paper, I use the phrase "biological design" unless otherwise qualified to mean the type of organized complexity produced by natural selection acting on blind variation.

not know which particular function that was. Was it to regulate body temperature, serve as armor, produce a colorful threat display, attract mates, or some combination of these effects?

The independence of design attributions from design explanations raises an interesting question: should our concept of "biological design" be indexed to selective etiology, much like the prevailing concept of function, or should it remain mechanism- and hence explanation-neutral? The definition of biological design given in the preceding section adverts to a history of selective shaping. But one might argue that it is a mistake to incorporate the *explanans* (cumulative selection) into the explanandum (biological design), lest the explanans fails to explain. If this is correct, then it seems that we should prefer a concept of biological design that does not entail any particular explanans, and which remains distinct from our concept of biological function and our ability to impute specific functions.

2.3 The Cognitive Foundations of Biological Design Attributions

How is it that we come to recognize natural design without knowing anything about the processes that gave rise to it? Do the same cognitive faculties implicated in the recognition of objects qua artifacts also play a role in the identification of biological design? While there are no definitive answers to these questions, a growing body of psychological research indicates that design thinking in relation to the living world is closely connected to the specialized faculties that subserve cognition in the domain of human artifacts.

Aristotle held that all things have a 'final cause'—a purpose or reason for existing. On this view, rain exists to nourish plants, plants exist to nourish grazing animals, and grazing animals exist to nourish humans. Pre-school children might aptly be described as natural Aristotelians in that they are inclined to attribute purposes not only to artifacts and living things, but also to inanimate natural objects such as clouds, mountains and streams. Deborah Kelemen (1999) refers to this tendency as 'promiscuous teleology'. Kelemen argues that promiscuous teleology is a byproduct of other cognitive adaptations, such as an innate bias toward agency detection. Her idea is that humans have an innate, adaptive capacity to make inferences about the goals, intentions and purposes of agents and artifacts, and that promiscuous teleology results from this capacity being extended to epistemically unwarranted domains, such as objects whose behavior can be explained by reference to purely physical (non-mental) causes. Most educated people abandon the teleological stance toward inanimate objects by the time they reach adulthood. In contrast, perceptions of the living world often remain teleological throughout life, reflecting (on Kelemen's view) overactive agency detection faculties that are recalcitrant to scientific education.

It is not clear, however, that overactive agency detection is the whole story when it comes to attributions of biological design. There is evidence that preschool children possess a specialized capacity for teleofunctional reasoning about organisms that is distinct from, and not a simple extension of, their ability to reason about agents and artifacts (Atran 1998). For example, by second grade, children tend to judge that features of a plant exist for the good of the plant, whereas they prefer physical explanations for the colors of gemstones (Keil 1994; Kelemen 2003). Furthermore, young children distinguish the 'internal' teleology of organisms from the 'external' teleology of artifacts. They judge that the features of an artifact are good for the maker or user of the artifact, rather than for the good of the artifact itself (Hatano and Inagaki 1994). For example, a thorn on the stem of a rose is judged good for the rose itself, whereas a barb on a string of barbed wire is judged good for its external human user.

It is ultimately unclear whether reasoning about organisms implicates the cognitive faculties that are implicated in reasoning about agents and artifacts. What is clear is that teleofunctional thinking plays a specialized, adaptive role in how humans reason about living things. For instance, young children use functional information—rather than overall similarity cues—to make inferences about the lifeways and behaviors of animals. In one fascinating study, Kelemen et al. (2003) presented preschool-age children with images of two insects—one a beetle (with small mandibles) and one an ant (with large mandibles)—and told them that the beetle hides from dangerous animals whereas the ant fights off dangerous animals. The researchers then presented the children subjects with a third image of a beetle with large mandibles, and asked them whether they think that it hides from or fights off dangerous animals. Despite the overall similarity between the two beetle images, the children overwhelmingly responded that the novel animal fights off dangerous animals—and where possible they offered functional justifications for that inference. From a selectionist standpoint this is not surprising, since functional information is often more predictive of organismic behavior than is overall similarity. In the language of contemporary biology, we can often infer more information about trophic position and behavioral ecology from a functional analysis than we can from a phylogenetic analysis (i.e., from genealogical relatedness). We can conclude from the formidable jaws of *Tyrannosaurus rex* that the animal behaved in ecologically important ways more like a tiger than it did like a brontosaur, despite its greater overall similarity to the latter.

Design thinking in relation to artifacts was adaptive, presumably, because it allowed us to predict how these devices interacted with other objects in the world. Similarly, by focusing on functional traits like teeth, horns, armor, camouflage, sensory apparatuses, and other 'inferentially rich' structures, early humans gained instant access to a wealth of ecologically relevant information about the probable behaviors of organisms. The clear adaptive value of teleofunctional reasoning about organisms makes incidental byproduct explanations look less compelling.

2.4 The Logical Foundations of Biological Design Attributions

To what extent can we say that inferences of intentional biological design emanate from deliberative mental processes, as opposed to intuitive faculties or lower-level cognitive biases? Note that to claim that design attributions are ‘reason-based’ in this sense is different from claiming that such attributions are ideally rational or epistemically justified, all-things-considered. Reasoning processes may give rise to fallacious inferences despite being rational in the non-ideal sense. Nevertheless, one way of approaching this question is to consider whether there are *any* epistemic contexts in which the intentional design inference is ideally rational. As it turns out, there is a long-standing philosophical debate over whether intentional design would be a rational explanatory inference in relation to the natural living world *if* there were no viable scientific alternative on offer.

William Paley (1802) imagined walking along a deserted shrubland and coming across a watch. Unlike a rock, whose nature and position can be explained as the outcome of chance processes, a watch contains numerous specialized parts exquisitely arranged so as to perform a particular function—an incredibly unlikely configuration that cries out for intentional explanation. Paley reasoned that like watches and other complex human artifacts, organisms are organized so as to produce precise specialized functions that could not plausibly result from a pure chance process. Paley was correct insofar as he held that chance or stochasticity is not a plausible explanation of ubiquitous functional complexity. If we compare Paley’s design argument to the ‘pure chance’ hypothesis, it looks very attractive. But if we compare it instead to the modern Darwinian alternative, it loses much of its force. Darwin’s great insight was that heritable traits vary in ways that affect organism-environment pairings, resulting in fitness differences between competing variants. Natural selection is precisely a *non-random* sampling process, even if the variation on which selection works is generated randomly with respect to its adaptive value. The explanatory virtues of evolutionary theory over intelligent design ‘theory’ have been extensively documented, and I will not rehearse them here (for discussions, see Dawkins 2009; Shanks 2004).

Skepticism of intelligent design preceded Darwinian theory. David Hume, for example, contended that the argument for intelligent design fails on logical grounds even though no credible mechanistic alternative had, at the time of his writing, been discovered. According to Hume, the argument for design is an argument from analogy between organisms and artifacts, which proceeds as follows: we observe a similarity in *structure* between organisms and artifacts—in particular, both exhibit a “curious adapting of means to ends”—and then we infer from this structural similarity to a similarity in *origins*. Since we know that artifacts originate in the plans and intentional actions of rational beings, we likewise infer that organisms originate in the plans and actions of rational being(s) whose product “resembles ... though it much exceeds, the productions of human contrivance” (Hume [1779] 1947, 143). Hume argued that this argument from analogy fails because the organism is a fundamentally different kind of thing than even the most complex human artifact.

Hume's reply misses the mark because organisms and artifacts could differ substantially in many respects (e.g. growth) even while both exhibit an exquisite functional arrangement that is astronomically unlikely to have arisen by chance alone. In essence, Hume's objection to the design argument falls flat because, as Elliott Sober (2004) has shown, the most charitable interpretation of the design argument is not an analogical one, but rather a probabilistic inference to the best explanation. Sober glosses this inference in terms of a comparative likelihoods approach, which takes the following form: the design hypothesis is a better explanation than the chance hypothesis of some biological observation O (e.g. the vertebrate eye) if the probability of O given that the design hypothesis is correct is greater than the probability of O given that the chance hypothesis is correct.[5]

Sober argues that a fundamental problem with the design argument, even in the absence of a scientific alternative, is that it relies on certain implicit auxiliary assumptions about the causal powers or folk psychological properties of the alleged designer—assumptions that we are not permitted to feed into the likelihood assessment absent some independent line of evidential support. When intelligent design proponents point to the elegant construction of the vertebrate eye and intelligent design skeptics point to avoidable imperfections in the same (e.g. the blind spot), both parties are relying on assumptions to which they are not entitled—namely the desires, goodness, etc. of the designer—and then running an inference to the best explanation based in part on these unwarranted auxiliary assumptions. Thus, Sober concludes, we cannot say that observed biological design is more likely given the special creation hypothesis than it is given the chance hypothesis. If Sober is right, then Paley's argument for design foundered on logical grounds long before Darwin came along with a successful alternative.

Sober's analysis raises a serious problem not only for intelligent design theory, but also for its most prominent critics, many of whom have appealed to the ubiquity of sub-optimal design in nature as among the most powerful evidence against intelligent design. Sober (2007, 4) refers to this as the "no designer worth his salt" argument. Darwin's observations of sub-optimal design in nature motivated his skepticism of special creation, causing him to exclaim: "What a book a Devil's Chaplain might write on the clumsy, wasteful, blundering low [and] horridly cruel works of nature!" (quoted in Dawkins 2003). Stephen Jay Gould has defended this view, arguing that

> Ideal design is a lousy argument for evolution, for it mimics the postulated action of an omnipotent creator. Odd arrangements and funny solutions are the proof of evolution—paths that a sensible God would never tread but that a natural process, constrained by history follows perforce (1992, 21).

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[5] Sober's 'likelihood' reconstruction holds that "Observation O favors intelligent design over chance if and only if Pr (O/ID) > Pr (O/Chance)" (2004, 122). He adopts the likelihood approach over Bayesian methods because the latter require that we assign prior probabilities to intelligent design and chance, respectively, which could skew the analysis.

Sober's point, though, is that for all we know sub-optimal design could be the result of the quirky aesthetic preferences of the designer, or perhaps even a supernatural expression of humor. Given the inscrutability of the creator, all possible desires could be built into such auxiliary hypotheses, none of which can be independently confirmed, and which can be gerrymandered to achieve the desired result. This gerrymandering has the effect of rendering intelligent design theory untestable in principle.

Imagine, however, that we discovered a patch of DNA in all known organisms in which "Made by God" was spelled out in Hebrew letters using DNA nucleotides. Sober's argument implies that the 'the stamp of Yahweh' observation is no more likely due to intelligent design than it is due to chance, since introducing any auxiliary hypotheses about what a designer would be likely to do (e.g., the Creator would autograph or trademark His creations) would be contrived. But this does not seem right. The stamp looks like a clear-cut confirmation of the design hypothesis, even if intelligent design theorists do not take the absence of such a stamp as disconfirmation of their theory, and even if we cannot independently justify claims about the desires of the Creator. Imagine that in addition to possessing the stamp of Yahweh, biological design was far more elegant than that which is actually observed, and that there was no fossil record of transitional forms to speak of. Boudry and Leuridan (2011) argue, quite plausibly, that in such a fantastical case the design argument could in theory unify a range of observations and make testable predictions that render it superior to theoretical alternatives.

Perhaps the ideally rational position, were no viable scientific theory on hand, would be to conclude that there is in all probability a mechanistic law-like explanation for the generation of biological design that continues to elude us. As Lewens (2004, 163) notes, "it is better to remain content, as Hume did, with the mystery of adaptation… than [to introduce] an intelligent designer who designs through mysterious means." Although Kant remained agnostic to the causes of biological teleology, he asserted that the inference of intelligent design is rationally compelling and "squares with the maxim of our reflective judgment" (1790/2007, 228). Indeed, there is empirical support for the notion that inferences of intelligent design emanate from biological design attributions, rather than the reverse. The most frequent justification educated people give for intelligent design-leaning beliefs is that features of the living world appear as if they were purposefully designed. Michael Shermer and Frank Sulloway surveyed members of the Skeptics Society—a highly educated and scientifically informed sample—and found that around 30 % of self-identified skeptics who believe in God (a purposeful, higher intelligence that created the universe) do so because the living world appears as if it were well-designed (Shermer 2002).

There are, no doubt, many people who accept special creation as an empirically insensitive matter of faith. My point, however, is that biological systems present, so powerfully, as objects of design that even scientifically informed and logically minded people are liable to infer agentic forces behind their production. The inference of intentional design often flows from thoughtful deliberation and cannot be explained away as an example of promiscuous teleology or religiously motivated dogma. Next, I will show that the same structural similarities between organisms and artifacts that motivate attributions of intelligent design also make technological thinking useful in biological science.

3 Part 2: Technological Thinking in Biology: The Promise

Thinking of organisms in technological terms is central to inferential reasoning in ecology and evolution, as well as to the formulation and testing of selection hypotheses. Technological thinking plays an indispensable role in understanding biomechanical systems and the physical constraints on organismic design. And it is responsible for major 'weight-bearing' in the logical structure of evolutionary theory.

3.1 Organisms as Artifacts: The Case of Darwin's Moth

Technological thinking in biology can lead to specific predictions in ecology and evolution which, when vindicated, represent paradigmatic confirmations of the theory of natural selection. Consider the following case of an unusual moth hypothesized by Charles Darwin. Darwin was intrigued by a Malagasy orchid that kept its nectar at the bottom of a 30 cm-long trumpet-like structure. At the time, no insect was known that could pollinate such a flower. Noting this ecological design problem, Darwin drew upon a theory of coevolution between orchids and their insect pollinators to predict the existence of a giant hawkmoth with an improbably long proboscis (Micheneau et al. 2009).

The proboscis is a retractable, pipette-like structure through which insects lap up nutrient-rich fluids, such as nectar. Darwin hypothesized an evolutionary arms race between the length of the orchid spur and the length of the proboscis: where the proboscis is longer than the orchid spur, the moth is able to extract nectar without pressing its head firmly against the orchid and thus without pollinating it; conversely, where the proboscis is shorter than the orchid spur, the moth will be less capable of extracting nectar and thus less likely to attempt nectar extraction and thus less likely to act as a pollinator. The result of this competitive interaction is a lock-and-key fit between the proboscis and the orchid spur.

From the hypothesis of strategic interaction and careful observations of pollination activities, Darwin was able to make precise predictions about the length of the hypothesized proboscis and the organism to which it would be attached. Darwin's hypothesized moth was discovered many years after his death (it was named *Xanthopan morganii praedicta*, after Darwin's prediction), and was not conclusively implicated as the pollinator in question for another century. Thinking of the proboscis as a 'tool' that is optimized by natural selection for extracting a desired resource, and of the orchid spur as responding in kind to 'technological advances' in the proboscis, was undoubtedly a significant cognitive factor in the formulation of Darwin's hypothesis. The very notion of an evolutionary 'arms race' or 'strategic interaction' conjures an image of rational technological move and counter-move, albeit without intentionality and played out over evolutionary time. The example of Darwin's moth could be multiplied many times over, suggesting that technological thinking is not merely conceptual shorthand, but rather plays a substantive cognitive role in organizing adaptive hypotheses (see Sect. 3.3).

Technological thinking in biology has borne not only epistemic but also technological fruit. The field of 'biomimetics' seeks to emulate biomechanical solutions to common ecological design problems, and to put these solutions to work for human ends. For instance, researchers at Clemson University are using the moth proboscis as an engineering prototype for designing 'bioinspired' devices that can be used for probing, transporting and controlling liquids droplets of varying viscosity (Vatansever et al. 2012). The first telescope to significantly reduce chromatic aberration, introduced by English inventor Chester Moore Hall in the eighteenth century, was modeled on the structural solution deployed in the vertebrate eye. Presently, researchers are looking to the visuo-structural adaptations of mantis shrimp to improve synthetic polarizing optics, which are currently significantly outperformed by 'natural' biophysical solutions (Roberts et al. 2009). The field of robotics has long attempted to emulate insect mechanical structures and control architectures, albeit with limited degrees of success due more to matters of physical scale than to the limits of technological thinking (Ritzmann et al. 2004). In short, artifacts serve as models for understanding organisms and their evolution, and organisms serve as models for designing and improving artifacts.

3.2 Two Worlds of Design

The case of Darwin's moth, and countless similar examples, show that in important respects, the worlds of organisms and artifacts are both worlds of design—and moreover, that it is fruitful to investigate them as such. There are profound differences, of course, between artifacts and organisms due to fundamental differences in the processes that produce them (Sect. 4.1). But analogies are not to be regarded as true or false—rather, they are more or less useful for inferring, understanding, explaining or predicting the properties of objects. Analogical reasoning between organisms and artifacts is useful because it taps into important non-accidental similarities between these kinds. For example, the cambered wing foil of birds and airplanes (discussed below) is not a coincidental similarity—it is a robust structural result of physical constraints on flight acting in conjunction with a function-optimizing process.

Given the non-accidental similarities between natural and artifactual design, it is understandable that many reasonable people would infer the existence of a biological designer in the absence of a credible alternative explanation. Somewhat more surprising is that organism-artifact comparisons did not cease after Darwinian theory garnered widespread acceptance. In some areas of contemporary biology, thinking of organisms as engineered artifacts is cognitively indispensable. The field of biomechanics, for example, sets out to investigate the structure of 'living technology'. According to Steven Vogel, Duke University biologist and pioneer of the field, "life forms a technology in every proper sense, with a diversity of designs, materials, engines, and mechanical contrivances of every degree of complexity" (1998, 16). Organisms and artifices are subject to the same physical laws, pressures, temperatures, fluid mediums, gravitational forces, and so on.

If the 'design problems' facing certain evolutionary lineages are highly similar to those facing human engineers, and if the solution to these design problems are highly constrained by physical laws, then we might expect similar solutions to emerge in natural and artifactual design despite fundamental differences in their underlying modes of production. Convergent evolution between distant lineages, such as the independent origination of camera-type eyes in vertebrates and cephalopod mollusks, indicates that there may be a limited set of evolutionary solutions to common ecological design problems (Powell 2012; McGhee 2011; Conway Morris 2003). In some cases, the physical laws impose such severe constraints on viable functional design that processes as different as mechanistic natural selection and foresighted human engineering will tend to converge on similar solutions. This appears to be the case for the problem of resolving images from electromagnetic radiation (discussed above), as well as for alternative modes of forming images from waveform energy, such as echolocation. Scientists began experimenting with active sonar well before sophisticated echolocation systems were discovered in bats and cetaceans, which were subsequently used as a model for 'bioinspired' devices.

Shared physical and environmental constraints have underwritten significant convergence between organismic and artifactual design, as recounted in Vogel (1998, 17):

> Both bicycle frames and bamboo stems take advantage of the way a tube gives better resistance to bending than a solid rod. A spider extends its legs by increasing the pressure of the fluid inside in much the same way that a mechanical cherry picker extends to prune trees or deice planes. Both [living and artifactual] technologies construct things using curved shells (skulls, eggs, domed roofs), columns (tree trunks, long bones, posts), and stones embedded in matrices (worm tubes, concrete). Both use corrugated structures . . . to get stiffness without excessive mass—whether the shell of the scallop . . . or the stiffening structures of doors, packing boxes, and aircraft floors, or fan-folded paper and occasional roofs. Both catch swimming or flying prey with filters through which fluid flows-whether spiders or whales, gill-netting fishers or mistnetting birders.

Like their human-engineered counterparts, animal wings, themselves convergent in the history of life, tend to have 'cambered' airfoils (curved wing tops with flattened bottoms) for maximal lift and minimal drag. Physical constraints on locomotion through viscous fluids have resulted in the repeated evolution of the 'fusiform' shape (a spindle form that is tapered at the ends) in fish, Mesozoic marine reptiles, marine mammals, cephalopod mollusks, and human-engineered craft both submarine and aerial.

Organism-artifact similarities go beyond overarching morphology and descend to the particular 'nuts and bolts' of biological construction. Consider Vogel's (1998, 186–7) description of the bacterial flagellum:

> The base of the flagellum forms a driveshaft that passes through the cell membrane, connecting it to a rotary engine. And the membrane works like a proper set of bearings. The engine bears a curious similarity in both appearance and operation to our electric motors. It's even reversible. The whole thing—engine and corkscrew—either singly or in groups, pushes or pulls a bacterium around much the same way a propeller pushes a ship or pulls an airplane.

Such descriptions are rife with helpful technological and, in particular, mechanical metaphor. In other cases, the analogy between organisms and artifacts is more tenuous. If we define "engine" in broad functional terms as "a structure that inputs non-mechanical energy into mechanical systems," then muscles, motile cilia, and even sub-cellular organelles responsible for respiration and photosynthesis (such as mitochondria and chloroplasts) would count as "engines." Why, in any case, do we refer to mitochondria as "microscopic engines," instead of referring to engines as "macroscopic mitochondria?" The answer seems straightforward and straightforwardly cognitive: we use familiar concepts to understand, relate to, and convey information about the properties of unfamiliar objects. It is this cognitive phenomenon that gives technological thinking in biology its purchase.

3.3 Biological Value of the Technological Stance

We have seen how technological thinking is of great utility in formulating adaptive hypotheses, picking apart the casual structure of biomechanical systems, and identifying the physical constraints on the evolution of form. A number of authors (e.g. Dennett 1995; Ruse 2004) have defended what Tim Lewens (2002/2004) calls the "artifact model of the organism." This is a policy suggestion for biological inquiry recommending that biologists investigate organisms as though they were artifacts, despite the significant dissimilarities between these ontological domains. The artifact model is motivated by a fundamentally pragmatic claim about the best way for biologists to unpack the causal structure of the living world. It is not motivated by a claim about how organisms are *in fact* constructed. It may turn out that organisms are composed of many useless and cumbersomely interconnected parts—but the idea behind the artifact model is that we approach organisms *as if* they have reasonably well-designed structures that are crafted for specific, isolatable functional roles.

'Methodological adaptationism' (*sensu* Godfrey-Smith 2001) is the thesis that biological inquiry is most fruitfully conducted when organismic traits are approached as if they are functional. The 'technological stance' associated with the artifact model implies more than simply investigating traits as if they were selected for particular purposes. It cognitively capitalizes on approaching organismic features as if they were technical artifacts. For instance, biologists modeling the functional moth proboscis (discussed above) describe this structure as a "drinking straw," the fluid uptake properties of which depend on the action of a "sucking pump" in the moth's head (Monaenkova 2011). The drinking straw model of the moth proboscis, like so many similar models in biology, relies heavily on an analogy to human artifacts for its cognitive purchase.

The technological stance structures our thinking about the nature of adaptive design. According to Michael Ruse, “for the natural theologian, the heart is literally designed by God— metaphorically, we compare it to a pump made by humans. For the Darwinian, the heart is made through natural selection, but we continue, metaphorically, to understand it as a pump made by humans” (Ruse 2004, 265). Vogel’s defense of the technological stance is even stronger: “We’ve only rarely recognized any mechanical device in an organism with which we weren’t already familiar from engineering” (1998, 311). If this is correct, then the technological stance will be vital to investigations in anatomy, physiology and cell biology, as well as to our understandings of evolution and ecology. It is only by using technological frames of reference that allow us to deploy concepts from more familiar domains of human experience that we are able to make sense of the staggeringly complex and unfamiliar causal structure of the organism.

Technological thinking also plays an important theoretical role in the structure of evolutionary theory. The philosopher Herbert Spencer famously characterized the process of natural selection as ‘survival of the fittest’ (without objection from Darwin), from which a logical problem ensued. If we define relative fitness in terms of reproductive success—wherein the fittest organisms are those that survive and reproduce—then we have rendered the principle of natural selection tautologous and hence non-explanatory. There is a voluminous and sophisticated literature in the philosophy of science addressing the ‘problem of fitness’ from numerous angles. One of the more promising strategies for avoiding the tautology problem equates fitness with probabilistically expected (rather than actual) reproductive success. The fittest are not those organisms that survive and reproduce, but those that have relatively higher values of expected reproductive success. This allows us to distinguish differential reproduction (‘sampling’) that is due to fitness differences (‘selection’) from differential reproduction that is due to other factors (‘drift’). The technological stance enters into the picture when we attempt to assign relative fitness values and appeal to these differences in order to explain differential reproduction.

Biologists often determine relative fitness values through the perspective of an ‘ecological engineer.’ Dennett (1995) has proposed that we define relative fitness in terms of the ability to solve design problems set by the environment. The design problem cannot, of course, be reproductive success simpliciter, as this would be to slip back into the Spencerean tautology. Biologists must instead specify the *ecological design problems* that a particular organism needs to solve—e.g., what it eats, how it forages, what predators it must avoid, how it reproduces, and so on—and from this information determine the relative fitnesses of competing variants in a population.

Fitness values are a function of the relation between organismic features and environmental properties, and no trait is fit in all environments—for example, sometimes being bigger or smarter is advantageous, and sometimes these traits are disadvantageous. For this reason, fitness must be assessed on a case-by-case basis, and the principle of natural selection will only admit of testable predictions once the ecological details are filled in and the engineering analysis takes shape (Brandon 1990, 20). Thus, it is mainly by recourse to technological thinking that the causal connection between heritable variation and differential reproduction is hypothesized and, through careful observation, established. In fact, it is by way of a pre-theoretical engineering analysis that people come to recognize the ubiquity of adaptive match in the first place.

4 Part 3: Technological Thinking in Biology: The Pitfalls

4.1 Organisms as Machines

Despite the seemingly indispensable value of technological thinking in biology, adopting a technological stance toward the living world can also lead to serious problems. The notion that we should conceive of organisms as machines has roots in Descartes' philosophy of nature. In *Principles of Philosophy* (1644), he wrote "The only difference I can see between machines and natural objects is that the workings of machines are mostly carried out by apparatus large enough to be readily perceptible by the senses (as is required to make their manufacture humanly possible), whereas natural processes almost always depend on parts so small that they utterly elude our senses" (quoted in Vogel 1998, 40). According to Descartes, animals, as well as human bodies, are machines whose microscopic inner working can in theory be understood in mechanical terms. On the Cartesian view, organisms are not *like* machines—they *are* a type of machine.

Insofar as machine thinking implies only mechanistic as opposed to vitalistic causes, there is little basis for objection. However, when machine thinking engenders comparisons between organisms and what we might call "quintessential machines," such as automobiles and computers, one can begin to see the grounds for concern. Modern molecular biology is replete with quintessential machine imagery, with biological analogues of factories, assembly stations, engines, motors, pistons, pumps, blueprints, software programs, and the like. The worry is that such analogies will be extended beyond their domain of utility or, even worse (though less plausibly), transformed into an identity relation (Recker 2010).

All technical artifacts are machines in the sense that they are used to modify force. However, quintessential machines are more complex than simple machines (such as levers and wedges), and as a result of this complexity they exhibit interesting similarities to organisms. Both quintessential machines and organisms are composed of specialized parts and part types; both exhibit complexly organized functions; and both can behave teleologically. Yet there are profound differences between organisms and quintessential machines that run the risk of being obscured by machine thinking in biology.

Perhaps the most significant difference between organisms and quintessential machines lies in their internal organizational dynamics (Nicholson 2013). Organisms are self-organizing, self-reproducing, and self-maintaining systems. No such machines currently exist. Quintessential machines, such as airplanes, may have most of their parts replaced by external human engineers over time, but they are not capable of repairing and renewing their own parts as organisms do. In addition, organismic systems respond flexibly in ontogenetic time to environmental challenges they encounter—a type of adaptive plasticity that Vogel (1998, 241) refers to as "demand-responsive alteration." For example, muscles grow in response to stress and emaciate in its absence; callouses form in response to friction and dissipate in its absence; and so on. In comparison to organisms, quintessential machines are developmentally inflexible and structurally brittle. Although some autonomous machines exhibit very simple goal-directed behavior (such as heat-seeking missiles or drones), even the teleological behavior of "simple" animals, such as insects, has no parallel among quintessential machines. In all of these respects, technological thinking will tend to detract from biological understanding, rather than illuminate it.

Furthermore, as Lewens (2004) points out, another potential methodological pitfall of thinking of organisms as artifacts is that this may cause researchers to neglect the developmental interconnections between parts of the organism. Machines tend to exhibit highly modular designs that allow for modification of their components without disrupting the overall functioning of the system in which they are embedded. In contrast, the selective shaping (Sect. 2.1) of organismic form is constrained by gene-gene interactions, as well as the one-to-many relations of the genotype-phenotype map—cumbersome developmental complexities that have no analogues in the quintessential machine world. This is not to say that developmental modularity is not an important factor in evolutionary innovation and diversification (e.g., the segmented body plan of insects probably played an important role in the great evolutionary success of this clade). But as Gould and Lewontin (1979) warned in their seminal critique of adaptationism, neglecting these developmental interactions can obscure the historical constraints on natural selection in shaping organismic form.

Technological thinking can also cause one to overlook differences in process that lead to important differences in product. Quintessential machines are rationally constructed with a pre-specified goal in mind, assembled with standardized materials gathered from far and wide, and rapidly improved upon in space and time. Organisms, by contrast, are the outcome of a mindless, incremental and excruciatingly slow process of natural selection, working only with the materials on hand, and tinkering with existing structures and developmental systems even when they are poorly cut out for the relevant ecological task (Sect. 2.4). Further, unlike rational engineers who are able to go back to the drawing board when a design turns out to be impracticable or inefficient, natural selection is often path-dependent and deeply constrained by history. As a result, nature will often fail to set a gold standard for artifactual design.

4.2 Encouraging Unwarranted Inferences of Intelligent Design

A final difference between organisms and artifacts relates to the origins of their respective teleologies. The functions of artifacts are indexed to the beliefs, desires or uses of *external* agents, whereas the functions of organismic features are determined by non-rational processes that are *internal* to the system in question, such as the role that such features play in system maintenance and/or reproduction. Insofar as organism-machine analogies gloss over this distinction, they could have worrisome implications for biology education. If not qualified, technological thinking could encourage or reinforce unwarranted inferences of intelligent design.

Machine-related language, which is widely used in educational materials and science journalism, can readily be coopted by contemporary creationists as 'evidence' that scientists secretly embrace intelligent design (Pigliucci and Boudry 2011; Nicholson forthcoming). Intelligent design apologists, such as Michael Behe (2006), quite intentionally refer to subcellular processes as "molecular machines" and "assembly lines" with all the intentionality that such descriptions entail. Even if, as I have argued, technological thinking is indispensable to much of biological science, biologists should nevertheless pay heed to the current political climate and the wider social implications of how they characterize and communicate their findings. In this way, epistemological values and social values can come into conflict in the practice of science.

This raises the question: Is it possible to effectively communicate biological research to the general public without appealing to the language of quintessential machines? The prospect of banishing all vestiges of design thinking from biology education and communication is both unlikely and undesirable, given the deep structural similarities between organisms and artifacts (Sect. 3.2), and given the fact that human cognition is heavily disposed toward teleofunctional reasoning (Sect. 2.3). Nevertheless, research suggests that early elementary school children are capable of sophisticated forms of biological reasoning, including with respect to the conceptual precursors of complex evolutionary concepts like common descent, extinction and speciation (Nadelson and Sinatra 2009). Given that folk biological structures emerge early in human development and remain psychologically entrenched (Kelemen 1999), it is imperative that we provide an early and accurate conceptual foundation for biology education. Having said this, it is difficult to imagine teaching biology to children—be it anatomy, evolution, ecology or behavior—without recourse to technological thinking and broader teleofunctional concepts. Nor would it be desirable to do so, given the cognitive utility of such approaches. Rather, in both education and science journalism, the limits of technological metaphors should be expressly acknowledged, and the dissimilarities between natural and intentional design—both in process and in product—should be consistently underscored.

5 Part 4: Technological Thinking in Biology: The Perils

Thus far, we have explored the promises and pitfalls of technological thinking in biology. In this final and concluding section, we will look at some ethical implications of adopting a technological stance toward the natural living world.

5.1 Technology Made Human

It is not hyperbole to say that technology made us human. Only a handful of taxa are capable of transmitting socially learned behaviors across generations, and none but *Homo* is capable of a cumulative technological industry: the innovation, improvement and transmission of technical artifacts down the generations.

The ability to fashion tools from non-living or formerly living matter, such as stone, wood, bone and hide, was a crucial factor in the transition from bipedal chimp-brained Australopithecine ancestors to early humans. Reductions of the human gut, jaws and teeth, and corresponding enlargements of the neocortex, were possible in part due to the transmission of simple technologies that allowed for the hunting and butchering of game as well as the thermal processing of food. It was not until the upper Paleolithic that augmented capacities for cumulative culture gave rise to the high-fidelity/high bandwidth transmission of cultural innovation that culminated in human behavioral modernity (Sterelny 2012). Technological capacities further expanded with the population boom and specialization of labor that followed in the wake of the Agricultural revolution (Diamond 1997), and yet again during the scientific revolution. Today technology progresses at such a breakneck pace that older generations are compelled to acquire cultural innovations predominantly from their descendants, reversing the intergenerational flow of cultural information that characterized hunter-gather human populations for over a million years.

5.2 Ethical Implications of the Technological Stance

If we are, as our evolutionary history suggests, obligatory technovores, what could be morally problematic about adopting a technological stance toward the living world? By assuming a 'Technological Stance' (all caps) toward nature, I mean something more specific, and more specifically cognitive, than simply possessing robust technological capabilities. I mean an orientation toward the natural world that conceives of living things primarily in terms of their utility to humans. The Technological Stance is similar to what Heidegger called "Ge-stell," which is often translated as "enframing" (Zimmerman 1990). According to Heidegger, Ge-stell reveals living things as an undifferentiated pool of resources—a standing reserve of function ("Bestand") to be manipulated in ways that are instrumental to human ends. Natural objects present anonymously as things to shape and control; they are thereby "ontologically subordinated" to human function, and as a result their non-technical nature is concealed.

Is this a plausible description of modern scientific attitudes toward nature and, if so, is it morally objectionable? Heidegger tended to focus on physics because of its emphasis on quantification, universality and control. But his critique can be applied as well to the ongoing revolution in biotechnology (Schyfter 2012). 'Creative' biosciences, such as genetic engineering and in particular synthetic biology, present us with increasingly powerful ways of converting the natural world into 'living technology'. Humans have been producing living technology ever since the advent of selective breeding programs in the Agricultural Revolution. However, the new creative biosciences represent a significant break from these ancient efforts in their ability to bypass the random sexual recombination of genomes in order to carry out precise genetic modifications and even the de novo synthesis of entire genomes, promising exponentially greater control over organisms and their properties.

One important difference between synthetic biology and even the most sophisticated selective breeding programs is that it involves the application of rational engineering principles to organismic design. Instead of deriving new life forms by tinkering with existing living systems, synthetic biology aims to design organisms from the ground (or minimal microbial platform) up by compiling and drawing upon a standardized registry of biological parts. These 'building blocks' can be combined in numerous ways to produce organisms that are exquisitely tailored to human purposes (Endy 2005; O'Malley 2009). This engineering approach could make synthetic biology particularly susceptible to the Heideggerian critique, to the extent that, for its practitioners, "there do not exist living things; rather, there exist functions, which are transferable without limitations" (Schyfter 2012, 217).

It is clearly hyperbole to suggest that synthetic biologists do not recognize organisms as anything but standing reserves of function. Surely, people can and do view living things from multiple perspectives at the same time (more on this below). But suppose, for the sake of argument, that creative biotechnologies do encourage individuals to view organisms as ontologically equivalent to the inanimate material that we use to fashion ordinary artifacts. This would indeed raise a host of ethical concerns. First, and most troubling, it could entail that the interests of beings with moral standing—such as persons and sentient beings more broadly—are not taken into account as reasons for or against human action. The interests of factory-farmed animals are already disregarded in this way, insofar as agricultural animals are treated entirely as economic units of production. Perhaps the Technological Stance we are inclined to take toward animal domesticates partially stems from their pseudo-artifactual status. One worry, then, is that technological approaches toward the living world could exacerbate attitudes that encourage individuals to treat beings in ways that are inconsistent with their moral status. Secondly, adopting a Technological Stance toward non-sentient organisms could be morally problematic, not because it entails the direct neglect of any morally protectable interests, but because the technological manipulation of non-sentient beings could have harmful consequences for, or disvalue to, beings that do have moral standing. An example would be engaging in technological manipulations of the living world that lead to global ecosystem or climate disruptions.

But neither the mistreatment of beings with moral status, nor the dis-valuable manipulation of non-sentient living things, is *inherent* to the creative biological enterprise (Douglas et al. 2013). There is no plausible psychological basis to support the Heideggerian view that people cannot engage in technological manipulations of the living world while at the same time recognizing the intrinsic value and non-technical nature of the subjects of manipulation. The fact that in developed countries scientific experiments on human and non-human animals is justified, restricted, and prohibited on moral grounds, shows that we are capable of treating beings with moral standing at the same time both as moral subjects that are valuable in themselves, and as means to other valuable ends.

If we take the Technological Stance to be a pervasive, unqualified and all-consuming approach to the living world, such that nearly all of our interactions with living things are approached from the standpoint of utility to the neglect of genuine subjects of moral worth, then it is deeply morally problematic. But viewed in this way, it is clearly a straw man—an attitude that virtually no people, and certainly very few biologists, exhibit. Biologists are often among the most ardent conservationists, many having been drawn to biology out of a deep admiration for natural design—not a desire to remake or master nature. Many scientists are in the business of modifying naturally existing organisms with the hopes of finding treatments for disease, or ameliorating anthropogenic effects on climate change (*cf.* Buchanan 2011). The notion that biologists or biotechnological engineers have grown decreasingly mindful of the moral value of morally valuable beings is a sweeping and empirically implausible claim.

5.3 Does Nature Deserve Respect?

One might argue that engineering organisms to suit human ends is inherently disrespectful of nature, regardless of whether or not it disregards the interests of uncontroversial moral subjects (for such a view, see Boldt and Müller 2008). But just what sort of ‘respect’ is due to non-rational, non-sentient entities is unclear.

There is currently no widely accepted theory of moral status that gives significant moral weight to the purely biological interests of non-sentient beings (such as bacteria), or to non-individual collectivities (such as communities and ecosystems). Furthermore, the ethic of respect is closely tied to Kantian moral theory and the central importance such theories assign to autonomy, practical rationality, dignity, and consent. Because respect is tightly linked to rational agency and associated concepts, it is only tenuously applied to nonrational sentient beings, and not at all to non-sentient organisms. One might operate with a radically different notion of respect than is found in contemporary moral philosophy, such as, e.g., a broader “reverence for nature.” But in that case, the onus is on the proponent of such a definition to make a principled distinction between laudable or permissible biological interventions, such as treating an infection with antibiotics or selectively breeding crops for human consumption, and interventions that are allegedly inconsistent with the principle of respect for nature, such as the genetic modification or synthesis of organisms for the very same purposes. To my knowledge, no such principled distinction has been made.

In short, ontological enframing in the Heideggerian sense would be ethically problematic if it obscured the morally relevant properties of living things and thus caused us to treat beings in ways that are inconsistent with their moral status. But, as we have seen, there is little reason to think that technological attitudes toward non-sentient organisms must, or are likely to, lead to the disregard of morally relevant interests, or to the mistreatment of genuine subjects of moral worth.

6 Conclusion

In conclusion, the technological stance is of great theoretical, methodological, and cognitive value to various subfields of biology and biotechnology. If adopted overzealously or without qualification, however, it can cause us to overlook certain ontological or etiological properties of the organism or to falsely infer others. In extreme forms, a technological approach could encourage a perception that the living world is merely a standing reserve of function to be converted without limit into technology suited to human ends. Yet the veneration of nature, which compels us to tout biological design as the epitome of engineering excellence and to view human interventions in the genetic fabric of the living world as inherently disrespectful, is no antidote for the pitfalls and perils of technological thinking. For it, too, is a form of ontological enframing that conceals from view the botched and amoral character of natural design—perhaps the best evidence we have that Darwin solved, once and for all, that Mystery of Mysteries.

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References

Allen, C., & Bekoff, M. (1995). Biological function, adaptation, and natural design. *Philosophy of Science, 62*(4), 609–622.

Atran, S. (1998). Folk biology and the anthropology of science: Cognitive universals and cultural particulars. *Behavioral and Brain Sciences, 21*, 547–609.

Ayala, F. J. (2007). Darwin's greatest discovery: Design without designer. *Proceedings of the National Academy of Sciences, 104*(suppl.), 8567–8573.

Behe, M. J. (2006). *Darwin's black box: The biochemical challenge to evolution* (10th anniversary ed.). New York: Free Press.

Boldt, J., & Müller, O. (2008). Newtons of the leaves of grass. *Nature Biotechnology, 26*, 387–389.

Boudry, M., & Leuridan, B. (2011). Where the design argument goes wrong: Auxiliary assumptions and unification. *Philosophy of Science, 78*(4), 558–578.

Brandon, R. N. (1990). *Adaptation and environment*. Princeton: Princeton University Press.

Buchanan, A. (2011). *Beyond humanity*. Oxford: Oxford University Press.

Conway Morris, S. (2003). *Life's solution: Inevitable humans in a lonely universe*. Cambridge: Cambridge University Press.

Dawkins, R. (1997). *Climbing mount improbable*. New York: W.W. Norton & Co.

Dawkins, R. (2003). *A Devil's Chaplain: Reflections on hope, lies, science, and love*. Boston: Houghton Mifflin Harcourt.

Dawkins, R. (2009). *The greatest show on earth: The evidence for evolution*. London: Bantam.

Dennett, D. C. (1995). *Darwin's dangerous idea*. New York: Simon & Schuster.

Diamond, J. (1997). *Guns, germs, and steel: The fates of human societies*. New York: W.W. Norton.

Douglas, T., Powell, R., & Savulescu, J. (2013). Is the creation of artificial life morally significant? *Studies in History and Philosophy of Biological and Biomedical Sciences, 44*(4), 688–696.

Endy, D. (2005). Foundations for engineering biology. *Nature, 438*, 449–453.

Godfrey-Smith, P. (2001). Three kinds of adaptationism. In S. H. Orzack & E. Sober (Eds.), *Adaptationism and optimality* (pp. 335–357). Cambridge: Cambridge University Press.

Gould, S. J. (1992). *The panda's thumb: More reflection in natural history*. New York: W.W. Norton & Co.

Gould, S. J., & Lewontin, R. C. (1979). The spandrels of St. Marcos and the Panglossian paradigm: A critique of the adaptationist programme. *Proceedings of the Royal Society of London B, 205*, 581–598.

Hatano, G., & Inagaki, K. (1994). Young children's naive theory of biology. *Cognition, 50*, 171–188.

Hume, D. (1779/1947). *Dialogues concerning natural religion*. Library of Liberal Arts.

Kant, I. (1790/2007). *Critique of judgment* (N. Walker, Ed. & J. C. Meredith, Trans.). Oxford University Press.

Keil, F. C. (1994). The birth and nurturance of concepts by domains: The origins of concepts of living things. In L. A. Hirschfeld & S. Gelman (Eds.), *Mapping the mind: Domain specificity in cognition and culture* (pp. 234–254). Cambridge: Cambridge University Press.

Kelemen, D. (1999). The scope of teleological thinking in preschool children. *Cognition, 70*, 241–272.

Kelemen, D. (2003). British and American children's preferences for teleo-functional explanations of the natural world. *Cognition, 88*, 201–221.

Kelemen, D., et al. (2003). Teleo-functional constraints on preschool children's reasoning about living things. *Developmental Science, 6*(3), 329–345.

Kitcher, P. (1985). Darwin's achievement. In N. Rescher (Ed.), *Reason and rationality in natural science* (pp. 127–189). Lanham: University Press of America.

Lewens, T. (2002). Adaptationism and engineering. *Biology and Philosophy, 17*, 1–31.

Lewens, T. (2004). *Organisms and artifacts: Design in nature and elsewhere*. Cambridge, MA: MIT Press.

McGhee, G. (2011). *Convergent evolution: Limited forms most beautiful*. Cambridge, MA: MIT Press.

Micheneau, C., Johnson, S. D., & Fay, M. F. (2009). Orchid pollination: From Darwin to the present day. *Botanical Journal of the Linnean Society, 161*, 1–19.

Monaenkova, D. (2011). Butterfly proboscis: Combining a drinking straw with a nanosponge facilitated diversification of feeding habits. *Journal of the Royal Society Interface*. doi:10.1098/rsif.2011.0392.

Nadelson, L. S., & Sinatra, G. M. (2009). Educational professionals' knowledge and acceptance of evolution. *Evolutionary Psychology, 7*, 490–516.

Neander, K. (1991). Functions as selected effects: The conceptual analyst's defense. *Philosophy of Science, 58*, 168–184.

Nicholson, D. J. (2013). Organisms ≠ machines. *Studies in History and Philosophy of Biological and Biomedical Sciences, 44*(4), 669–678.

O'Malley, M. A. (2009). Making knowledge in synthetic biology: Design meets kludge. *Biological Theory, 4*(4), 378–389.

Paley, W. (1802). *Natural theology: Or evidences of the existence and attributes of the deity.* Collected from the Appearances of Nature, Reprinted Gregg, Farnborough, 1970.

Pigliucci, M., & Boudry, M. (2011). Why machine-information metaphors are bad for science and science education. *Science & Education, 20*(5–6), 453–471.

Powell, R. (2012). Convergent evolution and the limits of natural selection. *European Journal for Philosophy of Science, 2*(3), 355–373.

Recker, D. (2010). How to confuse organisms with mousetraps: Machine metaphors and intelligent design. *Zygon, 45*(3), 647–664.

Ritzmann, R. E., Quinn, R. D., & Fischer, M. S. (2004). Convergent evolution and locomotion through complex terrain by insects. *Arthropod Structure & Development, 33*, 361–379.

Roberts, N. W., Chiou, T. H., Marshall, N. J., & Cronin, T. W. (2009). A biological quarter-wave retarder with excellent achromaticity in the visible wavelength region. *Nature Photonics, 3*(11), 641–644.

Ruse, M. (2004). *Darwin and design: Does evolution have a purpose?* Cambridge, MA: Harvard University Press.

Schyfter, P. (2012). Standing reserves of function: A Heideggerian reading of synthetic biology. *Philosophy and Technology, 25*, 199–219.

Shanks, N. (2004). *God, the devil, and Darwin: A critique of intelligent design theory*. Oxford: Oxford University Press.

Shermer, M. (2002). *Why smart people believe weird things*. Holt.

Sober, E. (2004). The design argument. In W. Mann (Ed.), *The Blackwell companion to philosophy of religion*. Malden: Wiley-Blackwell.

Sober, E. (2007). What is wrong with intelligent design? *Quarterly Review of Biology, 82*(1), 3–8.

Sterelny, K. (2012). *The evolved apprentice: How evolution made humans unique*. Cambridge, MA: MIT Press.

Vatansever, F., et al. (2012). Toward fabric-based flexible microfluidic devices: Pointed surface modification for pH sensitive liquid transport. *Applied Materials & Interfaces, 4*(9), 4541–4548.

Vogel, S. (1998). *Cats' paws and catapults: Mechanical worlds of nature and people*. New York: W. W Norton and Co.

Zimmerman, M. E. (1990). *Heidegger's confrontation with modernity*. Bloomington: Indiana University Press.