Contemporary Debates in Philosophy of Biology

Francisco Ayala and Robert Arp, Editors

Part II: Have Traits Evolved to Function the Way They Do Because of a Past Advantage?

No - Traits Have Not Evolved to Function the Way They Do Because of a Past Advantage

By Robert Cummins and Martin Roth

I. Introduction

What is the word 'function' for in the question above? If we replace 'function' with 'effects,' our answer to the question is 'Yes,' for then all the question is asking is whether natural selection explains evolution. So what's the issue? We take it that what the question is really asking is this: Is there a difference between having effects and having a function, and does natural selection ground the distinction? Our answer is that there is a difference between merely having effects and having a function, but that natural selection does not account for the difference.

A useful way to approach the issues to be discussed is to focus on function attributions. We attribute functions to things all the time; what motivates such attributions, and under what conditions are such attributions correct? As we see it, there are two constraints on function attributions:

(1) Explanation: Traits have many effects, but not all of those effects count as functions. Certain effects are called functions because of the explanatory role of appeals to those effects.

(2) Normativity: To attribute a function to a trait is to do more than say what it does; it is to say what it is supposed to do, what it is for. Traits have many effects, but not all the effects traits have are effects they are supposed to have. Only the effects that traits are supposed to have count as their functions.

In this paper, we are going to describe two approaches to function attribution, which we will call *systematic* accounts and *selectionist* accounts, and defend the former against the latter.[1] We will find that this is something of an intramural debate: there is more agreement than disagreement about the main points. So part of what we will be doing is trying to put our finger on what all the shouting is about. In this section we en contrast systematic and selectionist accounts of the role of function attributions in explanation. In section II we argue (following Davies, %%) that selectionist explanations are special cases of systematic explanations, and thus are not an alternative to systematic accounts of functional explanation. In section III we contrast systematic and selectionist accounts of norms and discuss their relative merits. We argue that while systematic accounts provide an account of norms that can play a legitimate role in science, selectionist accounts do not. Section IV summarizes our main points.

A. Systematic Accounts of Functional Explanation

Systematic accounts are built around a characteristic explanatory strategy we call *functional analysis*. Here are some examples:

Assembly line: The capacity to produce a Ford is analyzed into an organized sequence of simpler capacities each of which is performable by unskilled/mechanical labor.

Cooking and calculating: A recipe/algorithm specifies an organized sequence of simple operations performance of which results in the desired dish/mathematical result.

Schematic diagram: An amplifier circuit is analyzed into capacitors, resistors, power supply, etc. connected in a way that generates an amplified circuit.

Circulatory system: The system is analyzed into various kinds of pipes (active and passive), pumps (mechanical and osmotic), and control systems (autonomic nervous system) in a

[1] Buller (1998) has argued that it is fitness, rather than selection, that is required to ground functions. Because our argument is directed against any theory of functions that appeals to past advantage, our arguments against selectionist accounts of functions apply to fitness accounts as well, and sometimes our points are couched in terms of fitness rather than selection.

way that explains how oxygen, hormones and nutrients are delivered to cells, and wastes are removed.

Computer: Computers need to be understood at many levels of functional analysis, from algorithm, through programs, interpreters/compilers, operating systems, firmware to circuitry and hardware. They are literally unthinkable without this kind of multilevel functional analysis.[2]

Glucose metabolism: Understanding insulin resistance has become a major research effort in response to the obesity epidemic in North America. Figure 1 show san example of functional analysis at work in this area.

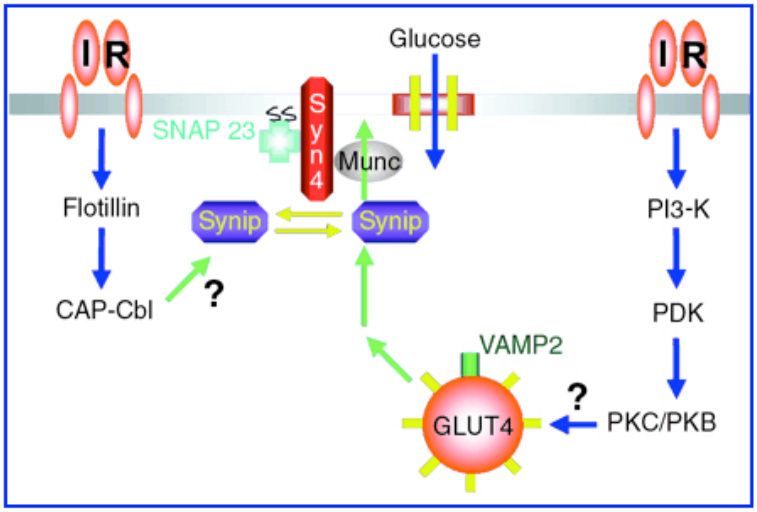

Figure 1 Schematic model indicating the presence of two potential insulin receptor–dependent signal transduction pathways. In this model, insulin stimulation results in the activation of a PI 3-kinase–dependent pathway that is necessary but not sufficient to induce GLUT4 translocation. In parallel, the insulin receptor activates an additional pathway leading to Cbl tyrosine phosphorylation through its interaction with the CAP protein. Syn4, syntaxin 4; PI3-K, PI 3-kinase. (J Clin Invest, July 2000, Volume 106, Number 2, 165-169. (Copyright ©2000 by the American Society for Clinical Investigation)

[2] Teleology is undoubtedly older than functional analysis, which probably did not become common until the introduction of relatively complex artifacts. It was then possible to think of natural systems as having a functional structure ("design") analogous to complex machines; indeed, to think of the body and its organs as natural machines.

In all these cases, a capacity of some complex system is explained as programmed exercise of capacities of system constituents, or as programmed exercise of other capacities of that system. All of these systems can do what they do because they or their constituent systems do other (typically simpler) things in a certain orchestrated way. Making a cake gets analyzed into stirring, adding ingredients, baking, etc. Signal amplification gets analyzed into the capacities of resistors, conductors, capacitors, power supplies, etc. This kind of explanation by analysis is *functional* analysis because it operates at a level of abstraction that identifies constituent processes or parts in terms what they do or contribute rather than in terms of their intrinsic constitutions: their functions rather than their forms.[3] Anything across which there is a drop in electrical potential is a resistor. Anything across which there is a pressure gain is a pump. Functional analysis is therefore a kind of black box analysis, where a black box is something whose internal structure is irrelevant to the explanation (and perhaps unknown), and which appeals only to what the interactors do—how they interact with each other.

Functional analysis allows us to understand how something—a circuit or circulatory—system works in abstraction from implementation details, e.g., in abstraction from how the resistor or pump itself works. The form-function distinction is evidently relative: the difference between an artificial heart and a natural one is one of form from the point of view of an analysis of the circulatory system. But natural and artificial hearts work differently, and hence themselves have different functional analyses, and these draw the form-function line in a different place. What is form at one level of analysis is function at another. Functional analysis at any level allows us to see how a complex system might be fixed, improved or sabotaged by substituting more or less adequate functional equivalents for component parts or processes.[4]

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[3] This is the sense of 'function' at the heart of functionalism in the philosophy of mind. The idea is that our mentalistic vocabulary is a functional vocabulary: it identifies mental states and processes in terms of what they do, not what they "are". Mental concepts thus resist physical reduction for the same reason function concepts generally resist reduction: physically disparate things can have the same function. Since the prospects for physical reduction for *doorstop* are no better than they are for pain or belief, and since no one wants to be a dualist about doorstops, failure of reduction is no argument for dualism.

[4] This, as it turns out, is just what we need to understand how natural selection works, a point to which we return below.

Systematic accounts are rather liberal about function attribution: functions are just the top half, as it were, of the form-function distinction: we have function rather than form when one is distinguishing what something does from what it is. Since containing systems may have different properties or capacities that want analyzing, and since something may be a constituent of more than one containing system, things can have a multitude of functions relative to one or many containing systems. Relative to a system of medical diagnosis, the function of the heart may be to make thumping noises. That may be one of the things one needs to know to understand how that kind of medical diagnosis works. To some, this seems promiscuous: "*That's* not the *(the!)* function of the heart! That's not what the heart is for," they say. "*The* function of the heart is to circulate the blood. Systematic accounts cannot pick out *the* function of the heart from all the other things hearts do." We agree: it cannot. And we think this is as it should be. The idea that the heart is *for* something in particular is, we think, a vestige of an unscientific teleology.

It is, or course, perfectly possible to acknowledge that what we are calling functional analysis is both a useful and a ubiquitous form of explanation in science and engineering, while denying that the analyzing capacities appealed to in such explanations are *functions*. That is, one could acknowledge what we are *calling* functional explanation without agreeing that it is *functional* explanation—explanation by appeal to functions—and hence without accepting our rather liberal account of function attribution. One could, for example, call it explanation by black box analysis. Indeed, we are pretty sure that this is the majority position. In a later section, we will try to explain why we think the majority position is gives us a messy picture of the relevant science. But it is really the explanatory strategy we are attached to. The rest of our position is mainly negative: it consists of what we do not like about selectionist accounts of function attribution and explanatory appeals to functions.

B. Selectionist Accounts of Functional Explanation

Selectionist accounts hold that the function of a trait is the effect of having that trait for which it was selected. If the chain of magnetosomes in magnetotactic aquatic bacteria were selected for because they kept their anaerobic hosts from oxygen rich surface water, then the

function of those chains is to keep their hosts from oxygen rich surface water. Thus, selectionist accounts attribute function only where there has been selection—natural selection or, perhaps, artificial selection. The account is, therefore, biological and historical at its core: the current effects of a trait are irrelevant; what matters is the actual selection history. What we are calling functional analysis, may appeal to a sparrow's or an airplane's wings role in enabling flight, but, on selectionist accounts, a strange selection history could reveal this as a mistaken function attribution. We prefer accept the history but hold on to the functional analysis.

Functional explanation, according to selectionists, is simply what is called ultimate explanation in evolutionary biology. (Tinburgen, 1958) The occurrence of a trait is explained as the result of natural selection: it appeared in some ancestral population, and spread through that population because of the positive contribution it made to the fitness of its bearers. The proximal effect (or effects) for which the trait was selected and maintained in the population is (or are) its function(s). Magnetotaxic bacteria have magnetosomes because of the functions of those chains of magnetically polarized bits of ferrite.

Some caveats:

(1) Traits may, of course, spread through a population without being selected for. Such traits have no functions, according to selectionist accounts.

(2) The circumstances that account for the selection of a trait do not, of course, account for the appearance of that trait in the first place. Selection can only select what is already there. Thus it is not the appearance of a trait that functional explanation explains, according to selectionist accounts of function, but simply its spread through the population. Natural selection can, of course, explain the appearance of a trait as well, but this will not count as functional explanation on selectionist accounts, because "first appearances" must be explained by the selection of something else: the elements in the developmental recipe for that trait, as well as the recipe itself.

II. Functional attribution: Meeting the Explanatory Constraint

According to the selectionist, we can sometimes explain presence of trait in an individual or population by appealing to its function. So understood, selectionist explanation is apparently an instance of teleological explanation. The modern debate over functions (citations from Cummins, FA) was originally motivated by the suspicion that teleology—the idea that one can explain why something happens or why it is there by appeal to its function or purpose—is unscientific. Acorns do not grow into oaks because that is what they are supposed to do. Such explanations appear to appeal to intentions and *intelligent design*[5] of the kind that is either absent in nature or itself in need of explanation. Thus was born the philosophical project of *naturalizing* teleology, i.e. of rendering it commensurable with hardheaded physical science. Early efforts along this line such as those cited above assumed that appeals to functions get into science in the context of teleological explanation, so the project of naturalizing teleology carried with it the project of naturalizing functions. This is part of what we deny: functions, we think, have a life outside teleology, in functional analysis. In that context, they evidently have no need of naturalization. It is teleology that is suspect, and hence any appeal to functions that arises in the context of teleological explanation.

Teleological characterizations of biological traits are ubiquitous in science and everyday life: eyes are for seeing, ears for hearing, hands for grasping, teeth and jaws for chewing. Contemporary teleological explanations of biological traits go beyond merely attributing functions to traits, however. Such explanations attempt to account for the spread of a trait through a population by appealing to the function of that trait. In order for such attempts to succeed, there must be some process or mechanism whereby traits spread, and spread because of their functions.

Historically, it was the failure to find such processes or mechanisms that doomed teleological explanations in mechanics and developmental biology. Teleological mechanics attempted to explain motion in terms of the goals or "final causes" of objects, but Newton's gravitational explanation of motion showed that objects would move as they do regardless of their functions or goals. Thus appeals to function to explain motion were rendered idle, and final

[5] We use this phrase *on purpose* to emphasize that teleology as an ultimate explanatory strategy is still with us.

causes were banished from mechanics. Appeals to the behavior of goal directed inner agents ("entelechies") to explain biological development fared no better. Not only were such appeals regressive (since the behavior of entelechies itself was explained teleologically), but developments in cellular and molecular biology showed that organisms would develop as they did with or without entelechies. As in mechanics, development was shown to be insensitive to function, and so appeal to goals or functions was explanatorily empty.

Given the dismal track record of teleological explanations in science, why do teleological explanations hang on in evolutionary biology? According to the selectionist, appeals to function to explain the spread of a trait are legitimate because there is a function-sensitive natural process that spreads traits: natural selection. Since there is no real dispute over whether natural selection explains the spread of traits via the contribution of effects of traits to fitness, denying selectionist explanations of trait spread looks tantamount to denying natural selection. We have no problem with natural selection. So, if selectionists see functional explanation as simply a standard application of natural selection, then we can have no objections to selectionist accounts of functional explanation so understood. So why do we find selectionist accounts of functional explanation troubling? We do not have a deep, principled objection. Our objection is rather that what we will call *neo-teleology* (Cummins, **)—the idea that some traits are "there" because of their functions—tends to be misleading when coupled with standard examples of function. This objection has two parts. We have already covered the first in passing. Selectionist accounts of function restrict appeals to functions to selection scenarios, while we think appeals to functions in black box analysis—the abstraction from form and the focus on interactions in complex systems—is ubiquitous, important, and deeply entrenched. The suggestion that these are somehow not "real" functions is silly. The suggestion that there is more than black box analysis involved in the appeal to functions in evolutionary biology is another matter, and this brings us to the second part of our objection.

It seems obvious that wings are for flight. But it is not at all obvious that, e.g., sparrows, or birds in general, have wings because they enabled flight in an ancestral population. While it may be plausible to suppose that, at some point in time, a sub-population of the ancestors of today's birds developed wing-like structures ("proto-wings") that enabled a crude sort of flying,

those structures are nothing like contemporary bird wings. Contemporary bird wings are the result of selection acting on variations in wing structures all of which enables flight. Selection did not act on differences in function (enabling flight), but on differences in how well that functions was performed.[6] Since selection acted on variations in traits that all shared the same function, appeal to function cannot explain why traits, e.g. contemporary bird wings, are there.[7]

This objection can be avoided: One could retain the selectionist account of functions, and conclude that the function of the sparrow wing is not to enable flight. If selection is operating to discriminate among variants, it's *at the level of variation* that the relevant functions must be attributed: flight-in-this-particular-way vs. flight-in-that-particular-way. Those two functions are *not* shared by the two variants. But this tactic has its costs. It flies in the face of almost all of the function attributions we actually make, attributions that would be licensed by functional analysis. It seems obvious that the functions of biological traits, structures and designs are often known without knowing what, if anything, was actually under selection (vs. merely hitch-hiking) and for what (better flight, mate attraction, durability, developmental cost). This, we think, is because the for-function distinction is often pretty obvious: wings enable flight in sparrows, bats and butterflies. There are serious issues surrounding how to discover what is under selection and why. There seems no reason to burden our relatively transparent function attributions with these issues, while, at the same time, banning such talk from black-box analysis. What's to be gained? Does calling the effects of traits that explain their spread 'functions' provide any explanatory leverage that is not already provided by a combination of black-box analysis, selection and development We are skeptical that it does.

What biology needs are the resources to explain how the effects of an organism's traits in a particular environment contributed to the reproductive success or failure of that organism. In order to tell that story, biologists need to know what the various capacities of organisms were,

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[6] Even this is tricky: a variation in wing design might be selected for even though it did not improve flight, but, e.g., because it made wings more durable or less developmentally expensive, or more attractive to the opposite sex.

[7] Perlman (this volume) makes the point that since it was selection pressure for better flight that drove the design improvements in wings, the function of wings (in the selectionist's sense) explains why contemporary wings have *the specific designs they do*. We have no objection to this point.

how those capacities were exercised by organisms, and how the interaction of organisms with those capacities with a particular environment affected fitness. What biology requires, in short, is functional analysis. Of course, after having actually done the science, we can feel free to give a new name to those effects of traits that explain spread, if we wish (perhaps we can call them 'selectionist functions'). In so doing, we can say that the selectionist function of a trait explains why it spread throughout a population, but at the cost of trivializing the appeal to such a function, for now the selectionist function is simply being picked out as whatever effect it was that explains spread. Function attributions, so understood, do not do any additional work when it comes to telling the evolutionary story; they simply piggy-back on whatever the science reveals to be the relevant effects. The kinds of function attributions that functional analysis yields, by contrast, are not so dispensable, and for reasons selectionist accounts must admit. If the goal is to explain why a trait spread by appealing to certain of its effects, then we need to be able to show how those effects of traits contributed to the capacities of their containing systems (e.g. organisms), which is precisely what functional analysis delivers. And once we understand how something works in the way provided by a functional analysis, we understand how others might be constructed and how other instances of the same design could perform the same task, or do it better. Because the system and its components are specified functionally, We can see how substitution of functional equivalents at various points in the design, the result natural or artificial variability in heritable traits, can make incremental changes in the system while preserving its overall viability. This is precisely how we must understand a system in order to see how it can evolve by natural selection.

III. Functional attribution: Normativity

What is common to the selectionist and systematic accounts of function is that to ascribe a function to something is to do more than say what the thing does; it is to say what a thing is *for*, and thus what it is *supposed to do*. This is the sense in which functions are normative, and any account of function attribution needs to accommodate this normative dimension. In evaluating the correctness of function attributions vis-à-vis normativity, there are at least two questions to

keep in mind: (1) How well do such attributions square with judgments about cases, both in common sense and science? (2) How does the account of norms provided fare with respect to the role of norms in science generally?

A. Norms in Systematic Accounts

Systematic accounts relativize failures to function properly to a target explanandum: component x is failing to function properly, relative to a capacity C of the containing system S, if (other things equal) S fails to have C (or has a relatively diminished capacity) because of what x is doing. Thus, systematic accounts allow for a kind of relativized or instrumental normativity: what something needs to do for the containing system to do whatever is singled out in the target explanadum (e.g. multiply, produce Fords, block serotonin re-uptake). Because such accounts offer an ahistorical notion of norms, they can easily accommodate the intuition that people knew wings are for flight and eyes for seeing long before they knew anything about selection.

A common complaint against this view is that such accounts attribute (or would attribute) functions where common sense would deny them—such accounts are too liberal. For example, relative to a medical diagnosis, we would say that the function of the heart is to make a thumping noise. In attributing such a function, we are claiming that the heart is supposed to make a thumping noise. The objection is that hearts are not supposed to make thumping noises—that is not what hearts are for. We think this objection reflects the interest relativity of function attribution; some capacities of containing systems are emphasized more than others, and so when we talk about a/the function of a trait, we tend not to relativize the attribution to a capacity explicitly: the salient explanandum goes without saying. To damage systematic accounts, one needs to defend that idea some capacities, but not others, *really* count when it comes to function attribution. We think such a defense cannot be made, a point we will return to later.

A perhaps more serious objection to the instrumentalist view function induced normativity is that this sort of instrumental normativity-the you-ought-to-do-x-to-achieve-g sense-will not accommodate the fact that, e.g., a blind-person's eyes are still for seeing, or that the function of a sperm is to fertilize an egg even though few ever do it.

Begin with blindness. The objection is that since the eyes of blind people never perform the function of enabling sight, systematic accounts should deny that a blind person's eyes are for seeing (and thus deny that the eyes are not functioning properly). To us, this appears to rely on a type-token ambiguity. A blind person's eyes are not for anything in that individual. Eyes generally—the type—enable seeing. If, for reasons too gruesome to imagine in detail, our descendents are all blind, then eyes will be, like the appendix, vestigial. Like the appendix, they will have no function. They will have *had* one, but they will have lost it. The sense that the eyes of a blind person are for seeing is simply the recognition that other humans do see, and that the eyes are an essential part of the human visual system. Thus, the blind person's eyes are not functioning properly (assuming here that the problem is really with the eyes) because they are not functioning in the way required for humans to see. The eye is for seeing; the blind individuals eyes are not. The same can be said for color blindness, deafness, and so on.

The same treatment applies to the sperm case. Individual sperm are not for anything in an individual. Sperm generally—the type—enable reproduction. Imagine that cloning replaces sexual reproduction as the main form of human reproduction. Human sperm become vestigial. They lose their function. The sense that individual human sperm are for fertilizing eggs is simply the recognition that other human sperm do fertilize eggs, and that fertilization is an essential part of the human reproductive system. Thus, sperm that fail to fertilize eggs are not functioning properly (assuming here that the problem is really with the sperm) because they are not functioning in the way required for humans to reproduce. If we imagine a functional analysis of the reproductive system that is designed to explain reproduction, it will feature a sperm fertilizing an egg. That is what needs to happen for the whole thing to work. The analysis will say that the job of a cloud of sperm is to achieve fertilization, and will emphasize that the system makes up in numbers what is lacking in individual efficiency. Asking for the function of an individual sperm is like asking for the function of an individual oil molecule in the oil pan in you car. It reveals a misunderstanding of how the system actually works.

We have, to repeat, no objection to ultimate explanations; no objection, that is, to explaining why something works the way it does by appeal to development, learning and evolution. Admittedly, you can do this by refusing to treat the doings of constituents of complex

systems as functions, and save the word for selected-for effects of traits and structures. But you pay a two-fold price. You fly in the face of ubiquitous function talk in black box analysis, and you fly in the face of the fact, argued above, that functions, as ordinarily attributed, do not track selection, i.e., that selection is typically selection among things that share a function as functions are ordinarily understood. This doesn't make selectionist thinking wrong; it just makes it potentially misleading--not well posed to interface with the rest of science and common sense.

B. Norms in Selectionist Accounts

Selectionist accounts of functions face a serious problem when it comes to making sense of norms in science. The problem can be put in the form of a dilemma: either the selectionist account offers an account of the appeal to norms in science that differs from the systematic account, or it does not. If it does not, then the dispute about norms is just a dispute about capturing intuitions about cases. If it does, then it must offer some non-instrumental notion of what a biological trait or structure is for or supposed to to. But what on earth could this be, and how could we make sense of it short of saying that normativity is built into the very fabric of reality?

The virtue of systematic accounts is that, outside of perhaps biology and psychology, the only notion of norms that science is thought to need is the instrumentalist one that systematic accounts provide. It is the only one biology and psychology need as well. These sciences need to be able to explain how effects of traits contributed to the capacities of containing systems, and how the failure to produce those effects explains the failure of a capacity to be exercised (or how variations in effects of traits explain variations in the capacities of containing systems). The same point applies to the containing systems themselves. To say that a containing system is supposed to have a capacity is just to say that it's having that capacity is necessary for the exercise of some other capacity of a larger containing system. At no point do we reach an unrelativized effect or capacity that a trait or containing system is supposed to have.

Perhaps the selectionist can respond that, although function attributions are always relative to some capacity of a containing system, some capacities more important than

others—indeed, some are critical—in determining when it is appropriate (true) to attribute functions. But privileging the capacities of containing systems that mattered to selection gives us no normativity beyond the instrumental only if we can make sense of the idea that organisms are supposed to have those capacities in some unrelativized sense. We agree, of course, that we can make sense of the claim that a creature needed to have certain capacities in order to survive and reproduce, relative to a certain environment. However, short of saying that the point or purpose of living is to survive and reproduce—that is the ultimate goal of life—surviving and reproducing are just among the many things an organism does. But organisms are not *supposed to* be fit; to think otherwise reflects the pre-Darwinian mindset that ultimate ends or goals can be found in the natural world. But, of course, this is not what those championing selectionist accounts of functions have in mind. They rather have in mind that privileging selected for effects gives us an *explication* of the concept of function in evolutionary biology. It gives us an account that is in refelective equilibrium with normal informed function attributions in evolutionary biology. We doubt this: functions, as standardly attributed, do not track selection, as we pointed out above. But we wouldn't be impressed in any case. What Philosophy has to offer here, we think, is a conceptual framework that enables an economical and fruitful way to express and assimilate the science and methodology, not a set of conditions that "captures" our (or their) intuitions about functions. We think the systematic account is clearly superior in this respect. To repeat: we think the fundamental thing to understand about functions is that the form-function distinction allows a kind of abstraction that allows us to understand how complex systems work, and how they can be modified. Like Galileo's idea that geometry can discipline a system of representations in a way that mirrors the way nature disciplines a system of magnitudes, functional analysis is one the central intellectual innovations that makes science and technology possible.

It is dangerous to start thinking that natural objects or processes or structure are *for* something. It inevitably suggests intelligent design. And it should. For this, after all, *is* the only source of purpose. Our artifacts, actions and beliefs are often for something or other. But *we* are not for anything. Nor are our eyes of the flora that thrive within us.

IV. Summary

The following table summarizes the differences between systematic and selectionist accounts of functions:

	Systematic Accounts	**Selectionist Accounts**
Explanandum	Capacities or properties of complex systems	The occurrence or presence of a trait or structure in an organism or artifact
Explanatory strategy	By an analysis of components that abstracts away from implementation details and focuses on what they do: black box analysis (bb analysis)	By appeal to natural selection
Function attribution: Explanation	What something does in a particular bb analysis	An effect of a trait or structure that accounts for its having been selected for and/or maintained in a population by selection pressures.
Function attribution: Normativity	Relativized to the target explanandum: component x fails to function properly relative to a capacity C of the containing system S if (other things equal) S fails to have C (or has a relatively diminished capacity) because of what x is doing.	Fixed by selection history: failure to function properly is failure to manifest the effect(s) for which the trait/structure was selected.
Scope	Any venue employing bb	Evolutionary biology (and,

	analysis (every branch of engineering, medicine, physiology, ecology, chemistry, sociology, art, music, literature…. Pretty much everything except, perhaps, basic mechanics (?)	perhaps) artifacts)