Robust Processes and Teleological Language

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Abstract: I consider some hitherto unexplored examples of teleological language in the sciences. In explicating these examples, I aim to show (a) that such language is not the sole preserve of the biological sciences, and (b) that not all such talk is reducible to the ascription of functions. In chemistry and biochemistry, scientists explaining molecular rearrangements and protein folding talk informally of molecules rearranging "in order to" maximize stability. Evolutionary biologists, meanwhile, often speak of traits evolving "in order to" optimize some fitness-relevant variable. I argue that in all three contexts such locutions are best interpreted as shorthands for more detailed explanations which, were we to spell them out in full, would show that the relevant process would robustly converge on the same end-point despite variation in initial conditions. This suggests that, in biology, such talk presupposes a strong form of adaptationism. The upshot is that such shorthands may be more applicable in the physical sciences than the biological.

Keywords: teleology, function, biology, chemistry, thermodynamics, adaptationism

1. Introduction: The pragmatics of teleological talk

The challenge of explicating apparently teleological language in the sciences (that is, language which ascribes *ends* or *goals* to a process or entity) has begotten a rich and venerable philosophical literature. Yet, were one to survey the last thirty years or so of work on the subject, one would be forgiven for supposing that (1) such language is peculiar to the *biological* sciences[1], and that (2) within the biological sciences, the problem largely centres on a single, puzzling word: "function".[2]

It takes only a casual inspection of scientific journals and textbooks to see that the problem may not be quite so localized. Consider, for example, the following descriptions (drawn from chemistry textbooks) of *an alkyl migration* (figure 1), a molecular rearrangement in which a secondary carbenium ion rearranges to a more stable tertiary structure:

> "rearrangement ... takes place so that a more stable carbocation is formed" (Jacobs 1997, 96)
>
> "alkyl migrations occur in order to make a carbocation more stable" (Clayden et al. 2001, 983)
>
> "rearrangement ... entails the movement of hydrogen, alkyl or vinyl/aryl group ... in order to create a more stable carbenium ion" (Anslyn and Dougherty 2005, 674).
>
> "groups ... change positions in order to generate a more stable carbocation" (Sorrell 2006, 194)

[1] See Hull 1974, Ruse 2002 and Lewens 2007 for explicit statements of this assumption. To my knowledge, the only discussion of teleological language in the *physical* sciences in the philosophical literature is that of Wicken 1981.

[2] See Buller 1999a for a clear statement of the view that the "problem of biological teleology" is the problem of explicating "function". For numerous accounts of "function", see Allen et al. 1998, Buller 1999b and Ariew et al. 2002. Recent accounts include those of Mossio et al. 2009 and Nanay 2010. Many authors now favour a pluralist approach regarding such accounts (see Godfrey-Smith 1993, Millikan 2002).

Such locutions, which seem to imply that the migration is explained by an end or goal of greater stability, suggest that assumption (1) may be a little hasty. While apparently teleological language may be *rarer* in the physical sciences than in the biological, it is not wholly absent.[3]

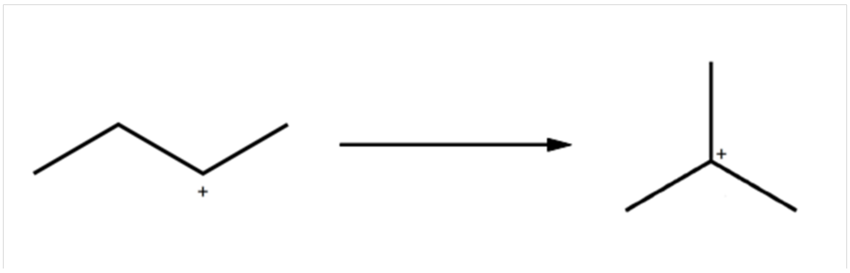

Figure 1. A simple alkyl migration in which $C_4H_9^+$ rearranges from a secondary to a tertiary structure.

What of (2)? Within biology, the notion of "function" is ubiquitous. But is *all* teleological language in biology a matter of ascribing functions? Consider the following examples from recent journal articles:

> "self-sacrifice evolved in order to minimize the risk of disease transmission" (Chapuisat 2010, R104)
>
> "sexual segregation has evolved in order to minimize the impact of parasites" (Ferrari et al. 2010, 1292)
>
> "Flowering time should evolve in order to maximize seed maturation success" (Chuine 2010, 3151)
>
> "In general, colour tends to evolve in order to maximize conspicuousness to potential mates with respect to background contrast." (Schwartz and Hendry 2010, 355)

[3] Talanquer (2007) has independently carried out a survey of teleological language in chemistry textbooks and has uncovered many more examples.

Such claims are striking for two reasons. One is their superficial resemblance to the preceding examples from chemistry textbooks. The second is that, on the face of it, they look to be doing something rather more controversial than ascribing functions. They look, prima facie, to be imputing an end or goal to an evolutionary process (specifically, the goal of *optimizing* some variable), just as the preceding examples from chemistry appear to impute end-directedness to an alkyl migration.

Examples of this sort do not refute (ii) decisively, for such talk might yet be *reducible* to function ascription: talk of a trait evolving "in order to" optimize some variable might be no more than an oddly oblique way of ascribing a function to it. I will consider this possibility in due course (see Section 4). For now, I merely want to emphasize that the reducibility of all teleological talk in biology to function ascription is not something we can safely take for granted. If we simply assume without argument that all teleological statements are function ascriptions, we risk glossing over important facets of explanatory practice in the sciences. In truth, I suspect that we are a long way from understanding the complex and varied roles of teleological language in the pragmatics of explanation. The detailed understanding we have accumulated regarding the multiple senses of "function" is a key component of that wider project—and by far the best-developed component at present—but not the whole story. I think there is plenty more work to do.

I want to make a small contribution to this wider project.[4] To be more precise, I want to suggest a novel account of the explanatory utility of the "in order to" locutions found in the examples quoted above. In both chemistry and biology, such locutions *look* to be imputing ends or goals to dynamic processes. But I don't think they are: I think the real explanatory function of such locutions is more subtle—and less dubious—than that. Moreover, I think the pragmatic function they serve is the same in both the chemical and biological cases. My suggestion, in broad terms, is that "in order to" locutions can serve to highlight salient features of trajectories across dynamic surfaces. I appreciate that, prior to a closer investigation of the

[4] Naturally, this project falls within a broader pragmatic approach to scientific explanation along the lines of van Fraassen 1980. I do not intend to defend the basic legitimacy of this approach here. For even assuming the tenability of a pragmatic approach to explanation, accounting for the pragmatic function of teleological language remains a significant challenge in its own right.

explanatory contexts concerned, this claim will sound strange. The rest of the paper spells it out more carefully.

2. How energy surfaces invite teleological shorthands

What can it be about an alkyl migration that invites teleological language? Plainly, it is not that carbenium ions have evolved by natural selection (they haven't), that they were designed by an intentional agent (they weren't), or that they are in any sense capable of goal-directed agency (they aren't). Thus, to explain why teleological language so often creeps into explanations of these processes, we must do more than round up the usual suspects. We may find the answer to be highly dependent on unusual features of the explanatory context in question. Alternatively, we may find that the case of alkyl migrations reveals something quite general about the pragmatics of teleological talk. I intend to argue for the latter possibility. First, however, we need to find that answer.

To do this, we need to consider what a more formal explanation of a molecular rearrangement (of which an alkyl migration is one example) would look like. What such an explanation *cannot* involve is any attempt to trace the actual causal history of any particular molecule, for such causal detail is inaccessible to us. How, then, can we go about explaining the rearrangement? How can we explain the outcome or end-point of a process in the absence of fine-grained knowledge of its causal trajectory? Here is one strategy: show that almost *any* causal trajectory would converge on that same end-point.

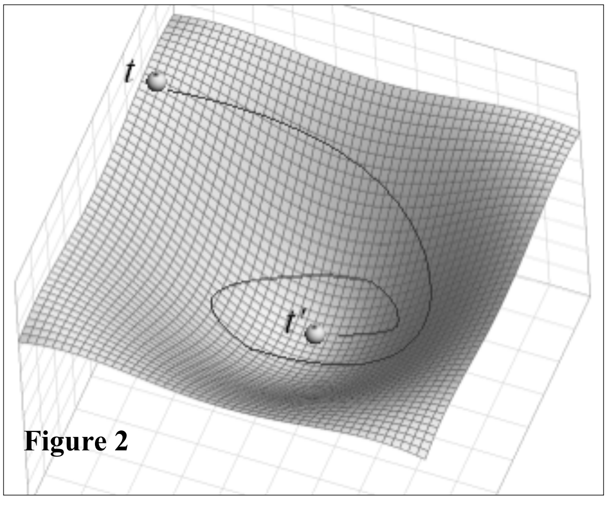

Figure 2

Consider a simple example. A ball is dropped on a landscape at time *t* (figure 2). It rolls around and, at time *t′*, comes to rest in the centre. Let's suppose we are ignorant of the ball's initial position: all we know is that the ball was dropped *somewhere* on the landscape and came to rest in the centre. Can we still explain why? Plausibly, we can. For we can see that the centre is the point at which the ball has *least potential energy*; we can also see that the surface is reasonably *smooth*, such that a possible route to the centre would have been available from almost any initial position. We therefore know that a ball would settle at the centre *almost regardless* of its initial position. And this looks, to me, like a pretty good explanation. Following Kim Sterelny (1996), I will call explanations of this sort (that is, explanations which emphasize robust convergence on an end-point, rather than fine-grained causal detail of the process by which that point was reached) *robust-process explanations*.[5]

Not *every* trajectory would converge on the same end-point, since, if the ball were placed right at one of the corners, it would drop off the edge. Note, however, that this does little to undermine the strength of the explanation. It seems enough that a *large range* of initial conditions and subsequent trajectories would result in the ball coming to rest in the centre. If the landscape were a *lot* more rugged, however, the explanation would be severely undermined. We can surmise, I think, that the quality of the robust-process explanation is a function of the smoothness of the landscape: the rougher the terrain, the more important it is to know the initial position of the ball and the precise topography of the surface.

Detailed explanations of molecular rearrangements (and chemical transformations more generally) proceed along broadly these lines. We may not know the fine-grained causal history of any particular molecule or set of molecules, but we can still compute a *potential energy surface* on which each point represents the energy of one possible configuration. By showing that a particular outcome represents a global *energy minimum* on this surface, and that this minimum was accessible (that is, not blocked by a

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[5] Sterelny's notion of a "robust-process explanation" bears similarities to Jackson and Pettit's (1990) notion of a "program explanation" and Sober's (1983, 1984) notion of an "equilibrium explanation". All three capture the general insight that an explanation may abstract away from fine-grained causal detail when an outcome is robust across variation in initial conditions; I adopt Sterelny's terminology only because it seems more felicitous in the present context.

prohibitively high potential energy barrier) from any likely starting configuration, we can explain the observed end-point (see Sieber et al. 1993 and Boronat et al. 1996 for detailed studies of the potential energy surface of $C_4H_9^+$, the ion shown in figure 1). This is just another instance of robust-process explanation.

The thought I want to develop is that talk of a molecule rearranging "in order to become more stable" is an informal way of conveying this robust-process explanation. Though I hope this strikes the reader as reasonably plausible (more plausible, at any rate, than the alternative, viz., that chemists really do impute goals to molecules!), I suspect that two concerns may arise. First, why should robust-process explanations invite teleological shorthands at all? Second, what makes such language *useful*, as opposed to simply misleading?

I think the first question is easily answered. When a process drives a system in such a way that the system has a robust tendency to converge on a particular end-point, the system will tend to evolve *as if* homing in on that end-point, even though the process driving the change may be wholly mechanical. A molecular rearrangement, provided there are no significant potential barriers blocking off the most favourable structures, is such a process: it is robustly *stability-maximizing* (or *energy-minimizing*). A molecule can thus be said to rearrange *as if* in pursuit of greater stability.

This line of thought suggests an answer to the second question. Why talk of ions rearranging from a secondary structure to a tertiary structure "in order to" get more stable, when one might just as easily say that they rearrange to a tertiary structure *because* the tertiary structure is more stable? How can a teleological locution *help*? The answer, I think, is that the teleological statement, though obviously less informative than a full and formal explanation of the process, still conveys more information than merely citing the stability of the tertiary structure. For talk of ions rearranging "in order to" to get more stable conveys not only that the tertiary structure was a stable end-point, but also that the stability of this end-point was the "driving force" for the whole rearrangement. It conveys, that is, not just that the end-point was stable, but that the process by which it was attained was thermodynamically driven and robustly energy-minimizing.

Of course, the locution is also potentially misleading: it risks creating the impression that the molecules are *really* seeking out the lowest-energy configuration. A trade-off is therefore needed: the benefit of conveying in shorthand the idea that a process is thermodynamically driven and robustly energy-minimizing must be balanced against the cost of sowing misconceptions. Chemists evidently think that, in the context of alkyl migrations, the pragmatic benefits of informal teleological talk outweigh the costs.

3. From chemistry to biology

In chemistry, teleological talk can serve as a useful way of indicating that a process is thermodynamically driven and robustly energy-minimizing. Could similar considerations help explain teleological language in *biology*? At least in some cases, I think they can. The clearest case is perhaps that of *protein folding*, a process with obvious affinities to the molecular rearrangements discussed above. These too are often explained, informally, in apparently teleological terms:

> "That proteins fold so as to minimize energy has been accepted for decades" (Crescenzi et al. 1998, 429)
>
> "Naturally occurring proteins fold so as to minimize free energy" (Gupta et al. 2005, 1328)
>
> "Our current perspective tracks back to Anfinsen's hypothesis that proteins fold so as to minimize free energy" (Rose et al. 2006, 16628).

Such turns of phrase can be rationalized in the same way as those considered above. Proteins do not pursue goals; but since protein folding, like much simpler rearrangements, is a thermodynamically driven and robustly energy-minimizing process—an exercise in converging to the minimum on a smooth (indeed, "funnelled"; see Bryngelson et al. 1995) energy surface—such language can serve as a useful shorthand. Indeed, Rose et al. explicitly make this clarification:

> "To characterize this hypothesis: under folding conditions, each protein slides down an energy gradient to the conformation that optimizes its constellation of favourable interactions, the native state." (Rose et al. 2006, 16628).

In this case, the teleological statement serves a shorthand for (or informal gloss on) a robust-process explanation.

But do such considerations apply more widely? In particular, do they apply in the context in which teleological language is most frequently found and on which philosophers have traditionally focussed their attention, viz., the context of *evolutionary* biology? This will turn largely on whether evolutionary dynamics underwrites robust-process explanations. We can break this down into two questions:

(i) Can an evolutionary process be modelled as the trajectory of a population across a dynamic surface?

(ii) Will the process robustly converge on particular end-points?

As Sterelny (1996) observes, there is a (not uncontroversial) tradition in evolutionary theory of answering both questions in the affirmative. It is widespread to consider evolution through the heuristic device of a *fitness landscape*, introduced to evolutionary theory by Sewall Wright (1932), and it is equally widespread to regard natural selection as a *hill-climbing process* which robustly drives populations towards fitness optima.

I do not intend to evaluate the legitimacy of such heuristics here (for discussion of the limitations of fitness landscapes, see Moran 1964, Lewontin 1978, Kaplan and Pigliucci 2006). I merely want to argue that, *if* we assume that selection may legitimately be viewed as a robust, hill-climbing process, then we can rationalize the kind of teleological statements canvassed in Section 1, that is, statements which claim a trait evolved "in order to" optimize some variable. For such statements will act as shorthands for robust-process explanations. Just as talk of molecules rearranging "in order to get more stable" implicitly conveys not merely that the outcome was stable but also that the rearrangement was thermodynamically driven and robustly energy-minimizing, so talk of a population evolving "in order to reach a fitness optimum" would convey not merely that the outcome was optimal but also that the evolutionary process was driven by selection and was robustly fitness-maximizing.

Consider the claim that "self-sacrifice evolved [in ants] in order to minimize the risk of disease transmission" (Chapuisat 2010, R104). I suggest that such a claim is, like the apparently similar statements one finds in the cases of molecular rearrangement and protein folding, intended as an abbreviated robust-process explanation. That explanation, were we to spell it out in full, would claim that (a) self-sacrifice was a product of a robustly fitness-optimizing process, viz., natural selection, and that (b) the trait was optimal because it minimized the risk of disease transmission. In general, I suggest that we can take the claim that some trait evolved "in order to" optimize some variable *X* to imply that (a) the trait was a product of a robustly fitness-optimizing selection process, and that (b) it was fitness-optimal in virtue of optimizing *X*.

4. Teleological language and adaptationism

This explication hints at a close relationship between teleological language and adaptationism. It seems clear enough that the rift between adaptationists and their critics must connect in some way to disputes regarding the legitimacy of teleological language, since adaptationists tend to find such language permissible, if not irresistible (see, e.g., Dennett 1995, Gardner 2009), while adaptationism's critics tend to deem it naive and unhelpful (see, e.g., Reiss 2009). If, as I have suggested, we interpret talk of a trait evolving "in order to" optimize some variable as a shorthand for an robust-process explanation, we can see clearly where the connection lies. For such talk would be premised on a brand of adaptationism Tim Lewens (2009) terms *good-designism*.

Lewens's "good-designist" allows that some evolutionary outcomes are inaccessible (pigs with wings, dogs with wheels) but insists that, such constraints notwithstanding, selection tends to generate phenotypes which are optimal among a *large range* of alternatives. Such a view is often associated with optimality modelling in behavioural ecology (see, e.g., Maynard Smith 1978, Grafen 1991); it also dovetails with a definition of adaptations as traits which are optimal among a range of variants (see Reeve and Sherman 1993, Gardner 2009). In fitness landscape terms, good-designism amounts to the claim that selection robustly drives populations towards optima. Populations are not blown hither and thither by contingencies, winding up marooned on islands of bad design. The good-designist thus appears committed to the rarity of cases where constraints and contingencies matter.

The validity of a robust-process explanation turns on the same considerations, and it is similarly imperilled when evolutionary outcomes are highly path-dependent. If my contention is correct—if talk of traits evolving "in order to" optimize a certain variable is indeed intended as a shorthand for an robust-process explanation—the legitimacy of such talk stands or falls with good-designism. If you think an evolving population, like a rearranging molecule, robustly finds a way to optimality, you should find the use of teleological locutions in biology fairly unproblematic. If, however, you suspect evolutionary outcomes tend to be rather more contingent than the good-designist likes to think, you should be sceptical of teleological language too.

5. The difference between "having a function" and "evolving in order to optimize a variable"

In the preceding sections, I have sought to move towards a deeper understanding of the role of teleological notions in the pragmatics of explanation by homing in on hitherto unexplored examples. I have noted some surprising locutions in scientific explanations of alkyl migrations, protein folding and evolutionary outcomes—locutions which appear to impute goal-directedness to the processes they describe—and I have appealed to the underlying dynamics of the processes concerned to explain why such locutions may be helpful rather than misleading. Teleological talk, I have argued, can serve as a useful shorthand when causal trajectories across dynamic surfaces robustly converge to a particular end-point in virtue of (a) the smoothness of the surface and (b) the end-point's representing an optimum for some variable.

If the story I have told is on the right lines, we learn from it something of the utility of such language in these specific contexts. But we also learn something about its hidden *assumptions*, namely, that the energy surface or fitness landscape in question is smooth enough to allow robust convergence on the same end-point. The surface need not be perfectly smooth, but it needs to be smooth enough for the precise topography to be explanatorily irrelevant. In the context of protein folding, this assumption is embodied in the *principle of minimal frustration*: the principle (advanced by Bryngelson et al. 1995) that the energy landscapes of proteins have a smooth, "funnel" shape devoid of "kinetic traps", local minima in which a protein may become disadvantageously lodged. In the context of evolutionary theory, as we have seen, this assumption amounts to a strong form of adaptationism.

It is this hidden assumption that can make talk of a trait evolving "in order to" optimize a variable dubious even when a function may be legitimately ascribed to that trait. This can be seen in cases in which an evolutionary outcome, though perhaps still locally optimal, is highly dependent on various constraints and contingencies. Consider the panda's thumb, Stephen Jay Gould's (1978) famous example of a "clumsy" trait, the result of selection working as "an excellent tinkerer, not a divine artificer" (1978, 30). The panda's thumb is not a digit: it is a hugely enlarged radial sesamoid, a type of bone that, in other mammals, stays in the wrist. It nevertheless manages to be quite good at stripping bamboo. It sounds reasonable enough to say that the panda's thumb has the *function* of stripping bamboo. But could we plausibly say that the trait evolved in order to maximize bamboo-stripping efficiency? The teleological explanation seems to ignore something important, namely that the form of the trait was highly constrained by the materials natural selection had to work with. Somewhere on the relevant fitness landscape, there may well have been a peak corresponding to pandas with well-adapted digits rather than hugely enlarged radial sesamoids, but, from their actual starting point, pandas simply could not get there. Though the trait may still represent a *local* optimum, contingencies and constraints were highly relevant in determining the end-point of cumulative selection. In these circumstances, function ascriptions remain possible, yet more richly teleological talk of traits evolving "in order to" optimize some variable becomes inappropriate.

Such cases make it plain that these locutions are more than oddly oblique ways of ascribing a function to a trait. They imply a substantive and contentious claim about the selection process by which the trait was produced, a claim that a mere function ascription (on any account of such ascriptions) does not imply. For talk of a trait evolving "in order to" optimize a variable implies that the process by which the trait was produced was robustly fitness-optimizing.

6. Conclusion

In explanations of molecular rearrangements—including the elaborate case of protein folding—teleological "in order to" locutions can usefully convey the information that a process would robustly converge on a particular end-point. They may, in principle, serve a similar function in evolutionary biology, but only conditional on a substantial form of empirical adaptationism. The use of such talk in biology thus amounts to an empirical bet that its adaptationist presuppositions obtain.

The upshot is that, while talk of a system evolving "in order to" optimize some variable is often pragmatically useful in chemistry (and biochemistry), its utility in evolutionary biology remains questionable. Hence, this form of teleological language, far from being the sole preserve of biology, may be more useful—and less misleading—in the physical sciences than the biological. This observation should, if nothing else, alert us to the errors embodied in assumptions (1) and (2). If we seek a full understanding of the pragmatics of teleological language in the sciences, we need to look beyond “function”—and beyond biology.

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