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The Biology of Logic

In *The Descent of Man* Charles Darwin made some remarks about 'Reason.' They begin

> Of all the faculties of the human mind, it will, I presume, be admitted that *Reason* stands at the summit. Only a few persons now dispute that animals possess some power of reasoning. Animals may constantly be seen to pause, deliberate, and resolve. It is a significant fact, that the more the habits of any particular animal are studied by a naturalist, the more he attributes to reason and the less to unlearnt instincts. . . . (Darwin 1871, p. 75)

The passage continues with an astute commentary on the evolution of Reason in humans and animals.

The discussion initiated by Darwin has continued to this day. It has grown into a sophisticated discourse of considerable fascination, drawing on several disciplines. It has delved into animal reasoning in general and human rationality in particular. I have no special quarrel with the details of this extensive literature, to which I have contributed. Nevertheless, regarding the whole, I cannot help suspecting that something akin to a Ptolemaic blunder has been made. The larger order of things has been misconceived.

The original Ptolemaic blunder was rectified by the Copernican revolution, an event that has long intrigued methodologists of science. Ptolemy had the heavenly bodies orbiting a still earth. Centuries later, Copernicus changed the course of astronomy by taking the sun to be the central stillness instead. At the time there were no new observational findings to prompt the change. It was a matter of interpreting the same empirical data from a radically different standpoint. A number of subtle explanatory economies combined to support the

heliocentric model. The acceptance of the new theory was gradual, and was abetted by a contemporaneous questioning of Aristotelian doctrines (Kuhn 1957).

Today, in the general drift of scientific thought, *logic* is treated as though it were a central stillness. Although there is ambiguity in current attitudes, for the most part the laws of logic are still taken as fixed and absolute, much as they were for Aristotle. Contemporary theories of scientific methodology are logicocentric. Logic is seen commonly as an immutable, universal, metascientific framework for the sciences as for personal knowledge. Biological evolution is acknowledged, but is accorded only an ancillary role as a sort of biospheric police force whose duty it is to enforce the logical law among the recalcitrant. Logical obedience is rewarded and disobedience punished by natural selection, it is thought. All organisms with cognitive capacity had better comply with the universal laws of logic on pain of being selected against!

Comfortable as that mindset may be, I believe I am not alone in suspecting that it has things backward. There is a different, more biocentric, perspective to be considered. In the alternative scheme of things, logic is not the central stillness. The principles of reasoning are neither fixed, absolute, independent, nor elemental. If anything it is the evolutionary dynamic itself that is elemental. Evolution is not the law enforcer but the law giver – not so much a police force as a legislature. The laws of logic are not independent of biology but implicit in the very evolutionary processes that enforce them. The processes determine the laws.

If the latter understanding is correct, logical rules have no separate status of their own but are theoretical constructs of evolutionary biology. Logical theory ought then in some sense to be deducible entirely from biological considerations. The concept of a scientific *reduction* is helpful in expressing that thought. In the received methodological terminology the idea of interest can be articulated as the following hypothesis.

REDUCIBILITY THESIS: *Logic is reducible to evolutionary theory.*

This is intended to apply at least to the ordinary, classical theories of logic, in a standard sense of reducibility to be explained.

To paraphrase, the hypothesis is that the commonly accepted systems of logic are branches of evolutionary biology. The foundations of logical theory are biological. The principles of pure Reason, however pure an impression they may give, are in the final analysis propositions

about evolutionary processes. Rules of reason evolve out of evolutionary law and nothing else. Logic is a life science. That is, of course, only an impressionistic gloss of the thesis; its exact meaning will have to be clarified as we go along.

The thesis might on first encounter seem dubious or even absurd. Certainly it is in need of interpretation and qualification. Nevertheless I hope to demonstrate that it has a core of truth that is entirely defensible. It would be too much to hope to establish it with finality in any single work, but the reasons for thinking it plausible and attentionworthy can be set forth. I beg the reader's suspension of disbelief until the chain of reasoning that supports the thesis can be laid out.

The issues involved are not vacuous. The philosophy of logic is at stake and perhaps the practice too. If as students of logic we indulge indefinitely the ancient habit of regarding logical principles as absolute and independent of biology, we will never think to look to evolutionary theory for a better understanding of them, or for ways of validating or refining them. The time may be ripe to look more seriously in that direction. If logic really is a matter of evolutionary dynamics, it should be so addressed.

It is only in recent years that it has become feasible to analyze logic from the standpoint of an advanced theory of evolution. Evolutionary biology is still young as an exact science. Parts of it have matured sufficiently by now, though, so that their ties with the foundations of logic have begun to emerge. The relationship has yet to be articulated to everyone's satisfaction, but it is sensed. This essay is my attempt to bring the ties into clearer focus, so that others may judge more easily whether a change of outlook is called for.

THE PROVENANCE OF LOGIC

Everyone will agree that something called Reason exists, is important, perhaps even "stands at the summit . . . of all the faculties of the human mind" just as Darwin said. It is also clear that this thing called Reason, whatever it may be, is based on principles called Laws of Logic. The puzzle is: *Where do the Laws of Logic come from?* That will be the topic question of our inquiry.

The answer to be proposed is that logical law comes directly from evolutionary law. That it does so is the intuitive content of the Reducibility Thesis. The hypothesis that logic is reducible to

evolutionary theory is a methodologically explicit way of saying, and providing a handhold for demonstrating, that logical principles follow in the train of laws of evolution.

In case the thesis still seems obscure, the spirit of it can be illustrated with a couple of hypothetical scientific questions and answers. The first question is, "How do birds manage to fly?" A full treatise on the subject would involve two different sorts of theory. One sort would have to do with the laws of aerodynamics – the physics of gases, the viscosity of air, slipstreams, loads, lift, and so forth. The aerodynamic theory would be needed to explain how the design of the wing succeeds. The other kind of theory would concern the evolutionary considerations that brought about the flight adaptation in birds and gave it its present form. It would take up how the selective forces associated with the advantages of flight acted on genetic variation to increase fitness in the population, causing the flight adaptation to appear and be refined. Topics such as population process models, measures of fitness, and evolutionary competition would be featured in this second part. Thus the answer as a whole would involve an interplay of at least two different sorts of principles, one the laws of aerodynamics and the other the laws of evolution.

The second question is, "How do humans manage to reason?" Since the form of this question is the same as that of the first, it would be natural to attack it in a similar two-pronged fashion. One part of the answer, which might naturally be placed at the beginning of a treatise on the question, would consist of logical theory. The different kinds of logic – deductive, inductive, mathematical, etc. – would be expounded and derived from first principles, perhaps in the form of axiomatizations of the various logical calculi. These ideal systems would be taken to define the rules of correct reasoning. The explanation of how humans evolved in ways that exploit these principles would come later on. The stages of adaptation to the rules of logic would be discussed, including some consideration of how well or poorly the human mind succeeds at implementing the fundamental logical principles set forth in the first part. Somewhere in the latter part there would be talk of selective forces acting on genetic variation, of fitness, of population models, etc. As with the former question, two distinct sorts of theory appear to be involved. There would again be two parts to the exposition, a first part explaining the laws of logic and a second the laws of evolution. All this seems, on the surface at least, in good analogy with the explanation of bird flight.

What the Reducibility Thesis proposes is that it is a *false* analogy. *There are no separable laws of logic*. It is tempting to think of the power of reasoning as an adaptation to separate principles of logic, just as flying is an adaptation to separate laws of aerodynamics. The temptation should be resisted. The laws of Reason should not be addressed independently of evolutionary theory, according to the thesis. Reasoning is different from all other adaptations in that the laws of logic are aspects of the laws of adaptation themselves. Nothing extra is needed to account for logic – only a drawing out of the consequences of known principles of natural selection.

It follows that the first part of the hypothetical treatise on how humans manage to reason – the pure logic – is superfluous. The second, evolutionary, part should suffice to tell what Reason is and where the principles of reasoning come from. The prolegomenon on logic can be omitted in favor of a unified treatment in which the laws of logic emerge naturally as corollaries of the evolutionary laws.

Moreover, if this *can* be done it *should* be done. At least, it should if one believes in Ockham's razor. It is a matter of explanatory economy, which is no less important here than it was for Copernican astronomy. If the reducibility hypothesis is correct, an explanation of reasoning need not import principles of logic from some alien venue as though they were a form of knowledge peculiar unto themselves. They are already fully implicit in known evolutionary principles, waiting there to be noticed and drawn out. The laws of logic are redundant in the presence of the laws of evolution.

Because it would be easy to mistake our purpose, I had better say what the purpose is not. The aim is *not* just to show that organismic reasoning ability is a product of evolutionary forces. That much is already obvious and it is hard to see how any Darwinian could deny it. The problem with such an assertion is not that it is untrue, but that it says nothing about where the laws of logic come from. It evades the topic question. It leaves the door open to the conventional conceit according to which evolutionary pressures mold the organism to preexistent, independent, logical principles descended somehow from some rational paradise. It is the latter presumption in its various guises that I wish to oppose. According to the Reducibility Thesis there is no such rational heaven. The laws of logic are neither preexistent nor independent. They owe their very existence to evolutionary processes, their source and provenance.

THE CLASSICAL FAMILY OF LOGICS

Actually, the hypothetical treatise on how humans manage to reason is not so hypothetical. In the chapters to follow, the attempt will be made to explain organismic reasoning in a manner respectful of Ockham's razor. The aim is a unified treatment in which the laws of logic are not introduced by fiat, nor drawn from some separate philosophical foundation, but emerge inevitably from the laws of evolution themselves. Different kinds of logic will then appear as manifestations of evolutionary laws at different levels of abstraction.

Deductive logic is probably what most people first think of on hearing the word 'logic'. Deductive reasoning is the kind of logic that offers argument forms in which conclusions follow from premises with (alleged) certainty. But deductive logic, though renowned in the pantheon of rationality, is only one constituent of a greater whole. The larger logical complex involves other formalisms including general *mathematics*. Deductive logic and mathematics are so intertwined that it has seemed to many to be an arbitrary matter where one sets the dividing line between them. Looking in another direction, deductive logic is also closely tied to probabilistic or *inductive* logic, the deductive being a sort of limiting case of the inductive according to one view. Statistical reasoning then elaborates probabilistic induction. Going a step further, probabilistic logic is implicated in *decision theory*. In the theory of decision under uncertainty, sometimes also called the 'logic of decision', probability theory is enhanced by the introduction of values called 'utilities' to provide a way of reasoning about the most coherent course of action a rational agent might take.

Each of these interrelated areas of logical theory presents a facet of rationality. It is the whole complex of such systems that is referred to in the Reducibility Thesis under the cover term 'logic'. The hypothesis is that they are *all* reducible to evolutionary theory.

Attention will be confined here to the standard, or 'classical', systems of logic. They are the common theories of deduction, probability, decision, and mathematics usually presented in textbooks and elementary courses and typically applied in practice. They are the logics that most mathematicians have in mind when attempting to formalize a proof, what most statisticians regard as foundational, what consultants commonly use to analyze management decisions, what artificial intelligence researchers most often build into their programs, and so on.

There are of course other kinds of logic than the classical, but to keep the discussion within bounds they will not be considered here. The better-known nonclassical systems include intuitionistic logic, modal logic, combinatorial logic, tense logic, many-valued logic, fuzzy logic, relevance logics, and other more specialized types of formalized reasoning. Whether some of these nonstandard systems might also be reducible to evolutionary theory is an interesting and perhaps researchable question, but not one that will be addressed in these pages.

It will be seen later that evolutionary theory gives rise not only to the classical systems of logic, but also to some generalized versions of the classical calculi with nonclassical properties. The status of these unfamiliar logics will be a matter for discussion later. For the moment they are mentioned only as additional candidates for the reduction. In summary, the Reducibility Thesis as it will be taken up here asserts that all the above-mentioned classical systems of logic, and also certain associated paraclassical systems to be described, are reducible to evolutionary biology.

BEHAVIOR AS COMMON GROUND

Decision theory is the branch of logic that comes into most immediate contact with the concerns of evolutionary biology. Decision theory and evolutionary theory are bound to each other by virtue of their mutual involvement with behavior. The concern with behavioral patterns provides a common boundary region between them.

The logic of decision is concerned with an agent's choice of the most reasonable course of action from a set of available courses of action. In decision theory a course of action is called an 'act', an 'option', or in complex cases a 'strategy'. But whatever it may be called, such a course of activity is a behavioral pattern of some sort. Now, behavior is something that evolutionary theory has much to say about. Behavior is observable, it is amenable to scientific prediction and explanation, and because it is a phenotypic property of organisms the possibility arises of explaining it in evolutionary terms. This makes behavior an interdisciplinary bridge approachable from both the biological and the logical sides.

The standard systems of logic – inductive logic, deductive logic, decision logic, and so on – are so tightly interwoven that the character of

the decision behavior posited in the decision-theoretic constituent of logic *determines* all of the remaining logic in the classical cluster. This may not be immediately apparent but will become clearer later. The upshot is that all of classical logic is closely tied to evolutionary theory and dependent upon it. If evolutionary considerations control the relevant aspects of decision behavior, and these determine in turn the rest of the machinery of logic, one can begin to discern the implicative chain that makes the Reducibility Thesis thinkable.

The general idea behind the reduction then is that evolutionary factors influence the character of reasoned behavior to the point of dictating it completely. Behavior is the fulcrum over which the evolutionary forces extend their leverage into the realm of logic. Viewed through the lens of biology, the behavior in question is evolutionarily fit behavior. Through the lens of logic it is rational decision behavior.

If the evolutionary control over the logic is indeed so total as to constrain it entirely, there is no need to perpetuate the fiction that the logic has a life of its own. It is tributary to the larger evolutionary mechanism. That being so, logic might as well be recognized outright as the branch of evolutionary theory that it is – momentous, but a branch nonetheless.

POPULATION PROCESSES INDUCE LOGICS

By *biology* we shall usually mean evolutionary biology. Within evolutionary biology the narrower focus will be on *population biology*, widely considered to be the mathematical core of evolutionary biology. Population biology includes the formal study of population process models, population genetics, selection, adaptation, and evolutionary fitness. The reducibility hypothesis could have been reworded to assert that logic is reducible to population biology.

The interplay between logic and biology comes down to this. Theories of population biology, when made precise, take the form of mathematical population process models and the properties deducible from them. One of their deducible properties, it will be seen, is that they spawn rules of logic. That is, particular population theories entail not just a tendency on the part of fit population members to obey external logical constraints, but the logical rules themselves. The population models determine what fit behavior shall be, under the conditions

postulated; and this fit behavior, regarded as decision behavior, determines the logic.

In this way the general evolutionary tendency to optimize fitness turns out to imply, in and of itself, a tendency for organisms to be rational. Once this is shown there is no need to look for the source of logical principles elsewhere, for the logical behavior is shaped directly by the evolutionary forces acting on their own behalf. Because the biological processes expressed in the population models wholly entail the logical rules, and are sufficient to predict and explain rational behavior, no separate account of logic is needed.

DEFINING REDUCTION

To say that logic is a 'branch' of biology, or that biology and logic are candidates for a 'unification', or that population processes 'induce' systems of logic, and so forth, is to speak loosely of a relationship that can be described more precisely as a *reduction.* Reduction has an honored place in science. It has been described as "the explanation or replacement of one scientific theory or branch of science by another" (Schaffner 1977, 146). It involves the grafting of one theory onto another in such a manner that the composite result is more economical of concepts and laws than the sum of the two original theories.

Historic examples of reducibility relationships include Newton's reduction of Kepler's planetary equations to the general laws of motion and universal gravitation, the reduction of Galilean mechanics to the same, the reduction of thermodynamics to statistical mechanics, and the reduction of parts of chemistry to particle physics. Mendelian genetics, or extensions of it, are thought by some to be largely reducible to molecular genetics. Methodologists still debate the details of these famous reductions, but few doubt that they are indeed scientific reductions in some sense or to some extent. In their time, all were first-class "Aha!" experiences.

The kind of reduction that will be relevant here is epistemological or nomological reducibility, or what is sometimes called *theory-reduction*. The general idea of a theory-reduction is that one theory is reducible to another just in case it can be derived from it by logical or mathematical steps without introduction of fresh subject matter. The simplest explicit characterization of theory-reducibility is the well-known model due to Nagel (1961) and others. Omitting some

refinements, a scientific theory T_2 is said in the Nagel model to be *reducible* to another theory T_1 if and only if (1) the concepts of T_2 can be defined in terms of concepts of T_1, and (2) using these definitions, the propositions of T_2 can be deduced from the propositions of T_1. Clauses (1) and (2) are the so-called conditions of *connectability* and *derivability*.

It is understood that the two operations can proceed in any number of stages. New concepts can be defined within the reducing theory, then new propositions can be derived with the help of the concepts just defined, then more new concepts can be defined with the help of the newly derived theory, and so forth until the theory to be reduced is eventually arrived at. Theory-reduction is a matter of derivability in any number of stages with allowance made for creativity of definition.

The formal Nagel definition is an oversimplification of what many actual theory-reductions are like. Some believe it to be a gross, even hopeless, oversimplification (Burian 1985, 25; Schaffner 1977). But it is adequate for simple cases and conveys the spirit of more involved reductions. Generalizations of it have been proposed and they may indeed appropriately broaden the scope of the original (Schaffner 1993). However, as it applies to the Reducibility Thesis, the modifications and extensions to the Nagel model that are needed are probably minimal. It would be premature to go into the exact formal details of the kind of theory-reduction required. Nagel's original characterization comes close enough to what is wanted for purposes of preliminary exploration.

The reduction of interest should not be confused with another kind of reduction to which it bears only a distant resemblance. There is a commonplace form of reductionism encountered in biology and ecology in which the properties of a biological system are analyzed hierarchically in terms of the properties of the system's members, physical components, or ecological subsystems. It is the type of reducibility referred to by G. C. Williams (1985) when he wrote "Reductionism is the seeking of explanations for complex systems entirely in what is known of their component parts and processes." The reduction of concern here is not of this mechanical kind. Although it may be possible to cast the sorts of reductions Williams refers to in the Nagel form, not all Nagel reductions are based on physical componential analysis. The theory-reduction of present interest has little to do with physical part–whole relationships and much to do with derivation and definition.