Introduction

Charles Darwin's *Origin of Species* (1859) argues for two big ideas, both expressed metaphorically: the 'tree of life' and 'natural selection'. New species of animals and plants have descended from earlier ancestral species; and these lines of descent with divergent modifications have branched and re-branched, like the branches on a tree. If all these lines trace to one first, common ancestral species, then all life forms one tree. Natural selection has been the main cause of these divergent modifications. By selective breeding, humans make, in a domesticated species, varieties fitted for different ends: strong, heavy horses for ploughing, and light, fast ones for racing. In the wild, over eons, natural selective breeding, due to the struggle to survive and reproduce ('the struggle for existence'), works unlimited changes in branching lines of adaptive descents, from fish ancestors fitted for swimming to bird descendants fitted for flying and mammals for running.

Our book is about Darwin's idea of natural selection. He called it that to mark the relation between selection in the wild and selection on the farm, or 'artificial selection'. Understanding this big Darwinian idea requires understanding his thinking about the relation between artificial and natural selection. Traditionally one considers, as Darwin did, how natural selection could be *analogous* to artificial selection, and how his argument from selection on the farm to selection in the wild could be an *argument by analogy*. But there are two difficulties. First, there is no consensus about what is meant by saying that two things are 'analogous', with specialists writing on Darwin no more in agreement than other writers on arguments by analogy. Second, several recent commentators have taken the radical revisionist line that, for Darwin, the relation between artificial and natural selection has been misidentified as one of analogy. But, once again, there is no consensus among these revisionists as to what the relation is.

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We hold that Darwin was indeed arguing by analogy on behalf of natural selection, and that his analogical argument conformed to the oldest, ancient Greek view of analogy: the view taken by Eudoxus and, following him, by Aristotle, who construed analogy as proportion, as repeated ratio, as relational comparison. What is new in this book is the first sustained interpretation of Darwin's selection analogy as belonging in this distinctive tradition in the structural and functional understanding of analogy. We conclude that, in arguing from artificial to natural selection, Darwin was doing analogy, and doing it Aristotle style; that this was a good thing for him to be doing; and that he did it very well.

By way of a brief introduction to analogy as proportion, consider three examples, moving rapidly from the mathematical to the causal, and from the unremarkable to the remarkable:

- 1 is to 2 as 5 is to *x*.
- Socks are related to feet as gloves are related to hands. Since socks warm feet, gloves, which cover hands as closely as socks cover feet, are correctly inferred to warm hands.
- Stockbreeders are causally related to their livestock as the struggle for existence is causally related to wild organisms. The causal relationships are, in other words, the same in kind. But since the stockbreeders' selective breeding (artificial selection) is much less discriminating, comprehensive and prolonged – and so less powerful – than selective breeding by the struggle for existence (natural selection), the causal relationships differ in degree. Where artificial selection, the weaker cause, can produce only new varieties within extant species, natural selection, the stronger cause, can be inferred to produce comparably greater effects: not merely new varieties but new species.

Familiarly enough, '1 is to 2 as 5 is to *x*' specifies a mathematical proportionality. If, as here, three of the four terms are given, then – shifting from analogy to argument by analogy – the fourth can be calculated from them. Not so, of course, with the gloves analogy, or with the struggle-for-existence analogy. In these examples, given any three terms, empirical inquiry is required to establish the fourth. Furthermore, the relations in these examples are not mathematical but causal relations. Concentrating on what concerns us here, artificial selection mediates between its causes – the stockbreeders' actions – and its effects, the changes wrought in domestic animals; while natural selection mediates between its very different causes – the struggles for existence – and its very similar effects, the changes wrought in wild animals. The four related terms are

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not quantities, but the analogy is four-term proportional; and so an argument from this causal analogy is an argument from proportionality such as Aristotle was the first to analyse and validate.

In what follows we hope to persuade readers that placing Darwin's analogical argument from artificial selection to natural selection in the context of this Aristotelian tradition illuminates not only Darwin's argument but a range of topics extending well beyond it. We must emphasise, however, that it is no part of our brief to suggest that Darwin structured his argument as he did because he read Aristotle, or any later writer on analogy as proportion. As far as possible, we trace how the young theorist came to construct his causal theorising in that way; but we have found no reason to think that he was following what was said by any logical or rhetorical authorities on Aristotelian analogy. We shall say more on this topic in our concluding chapter, but for now, a parallel may clarify this issue. Like many scientific theorists, Darwin often constructed arguments conforming to the logical form modus tollens, or denying the consequent: the form of argument where the falsity of a statement is inferred from the falsity of another consequent statement that it entails. But bringing what logicians have said about modus tollens over the millennia to the examination of a Victorian scientific thinker's argument does not require believing that they learned from a logic book about this way of arguing. And so likewise, in our view, for Darwin's constructing his excellent examples of Aristotelian analogies.

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Although this book is meant to be read straight through, an initial, high-altitude pass over its contents most usefully begins in the middle, with a trio of chapters (4–6) on the *Origin of Species*. Darwin called the *Origin* 'one long argument', and these chapters clarify how the whole argument is conducted, how Darwin's analogical reasonings about natural and artificial selection support his argument, and how his various metaphors are grounded in those analogical reasonings. Chapter 4 aims to show that Darwin structured the *Origin* as he did, and placed his selection analogising as he did within that structure, in conformity with a now unfamiliar ideal for the conduct of a scientific argument: the vera causa, or 'true cause', ideal. On Darwin's understanding of this ideal, it demanded, first, that the cause of interest be shown to exist, on the basis of evidence which is independent of what one is trying to explain; second, that, again on independent evidence, this cause is powerful enough to produce the effects

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to be explained, so that they *could have been* effects of this cause; and third, that this cause has *actually* been responsible for bringing about those effects. For Darwin, the argument by analogy from artificial selection to natural selection served to meet the second and third demands, by providing grounds for believing that, whereas selection on the farm could produce only new varieties within existing species, selection in the wild could go far further and produce new species.

Chapter 5 narrows the focus, from the overall structure and strategy of the *Origin* to this argument for the greater causal efficacy of natural selection compared with artificial selection. To secure this conclusion Darwin has to put in a lot of not-easy-to-follow work which, we suggest, is most easily grasped by seeing the argument as proceeding in two stages. In the first stage Darwin gives reasons for thinking that the same relation which holds between the stockbreeder and new varieties on the farm also holds between the struggle for existence and new varieties in the wild. In the second stage he gives reasons for thinking that, although the effects of the struggle will be the same in kind as the effects of the stockbreeder, the former effects can nevertheless be different in degree, accumulating to the point where not merely new varieties but new species are formed.[1]

[1] For readers eager for a more rigorous version: It is important to distinguish between Darwin's analogy and his argument based on that analogy. In its simplest form, Darwin's analogy has this structure:

The struggle for existence (B) is causally related to organisms in the wild (D) as the stockbreeder (A) is to organisms on the farm (C).

This is a statement of the analogy and not an argument to or for the analogy, nor an argument by or from it. Here, B and A may be called 'analogous' because, for some C and D, B is to D as A is to C. The two causal relations – natural and artificial selection – are analogous because their respective causes are.

Turning now to Darwin's argument, let us first consider the general structure of the simplest form of an argument from or by such an analogy:

A is F.

B is analogous to A.

Being F is invariant under this analogy.

Therefore B is F.

This is a valid argument form, so the strength of any argument with this structure depends on how well-justified the premises are.

Assimilating Darwin's initial argument by analogy to this structure gives us the following:

A stockbreeder (A) selectively breeds his or her animals and plants so that new domestic varieties are produced (is F).

The struggle for existence (B) is related causally to wild animals and plants (D) as the stockbreeder (A) is to his or her animals on the farm (C).

The same selective causal relation produces the same effect (being F is invariant).

Therefore, the struggle for existence selects in ways resulting in the production of new wild varieties.

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When Darwin dwells upon the contrast between the weaker causal power of the stockbreeder and the much stronger causal power of the struggle for existence, he occasionally helps himself to metaphorical language – 'Man can act only on external and visible characters: nature cares nothing for appearances, except in so far as they may be useful to any being', and so on. Chapter 6 provides an analysis of these and other metaphors in the first four chapters of the *Origin* with a view to exploring their argumentational functions. Attention to these metaphors, in tandem with the analogies which they express, can help deepen an appreciation both of the potentialities of the argument-as-proportion tradition and of Darwin's skill in exploiting those potentialities. As we will stress throughout, when it is *relations* that are being analogised, the pairs of items bearing those relations can be strikingly different from each other. Moreover, once an initial analogy is in place, it can suggest extensions, which in turn can suggest further extensions. Shakespeare was a virtuoso of metaphors underpinned by imaginatively extended relational analogies. But Shakespeare wrote plays and poems, not scientific arguments. What makes Darwin's metaphors remarkable – and even more virtuosic than Shakespeare's – is their disciplined fealty to the analogies that carry parts of Darwin's argument.

By way of preparation for these *Origin*-centred chapters, our opening chapters (1–3) set out long-run, medium-run and short-run background stories. The long-run story, in Chapter 1, starts with Pythagorean mathematics, and with work, ascribed to Eudoxus, on proportion. It then moves to Aristotle, who showed how analogy as proportion could be deployed in a wide variety of empirical contexts, and who completed the Greek founding of the tradition of analogical reasoning most pertinent to Darwin's argument practices. When Aristotle affirms, for example, that scales relate functionally to fish as feathers do to birds, modelling of similar triangles is still a pertinent precedent. But the mathematical limitations are transcended for all posterity. Moreover, Aristotle emphasises that analogies can support insightful, suggestive metaphors such as one from later classical times: if fins are to fish as wings to birds, and fins are to water as wings to air, then we may say metaphorically that fish fly in water and birds swim through air.

The medium-run story, in Chapter 2, concerns the century and a half before Darwin wrote the *Origin*. On the one hand, this Greek tradition was alive and well in Darwin's day. On the other hand, this tradition no longer had a monopoly on even elite understanding of analogical arguments, with consequences that have sown confusion ever since, down to

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our own day. In particular, it was in the later eighteenth century that the Scottish philosopher Thomas Reid introduced an account of such arguments based not on proportion but on similitude. Reidian analogy is similitude between known and inferred properties, whether relational or not. Saturn, Mars and other planets are known to resemble the Earth in orbiting and being lit by the Sun, in having their own moons and so on. Inferably, then, they probably resemble the Earth in being inhabited. According to Reidian analogy, if two or more objects are all known to have certain properties, they probably also share other properties that some of those objects are not known but may be inferred to have. The shadow of doubt that now falls over whether analogical arguments, Darwin's included, can ever be really strong arguments is largely of Reid's making.

These two initial chapters cover millennia, centuries and decades. With Chapter 3 the pace slows to years, months and days. Here we unfold the short-run background story to the analogical argument of the *Origin*, covering the quarter century from Darwin's earliest causal–analogical conjectures about species extinctions, in 1835, through his pre-1859 theorising about species origins. By mid-1838 Darwin, in his private notebooks, had been for months comparing and contrasting species being naturally formed in the wild with variety formation under domestication. In doing so he distinguished between natural domestic varieties formed in regional isolation as adaptations to natural local influences such as soil, climate and vegetation, and artificial domestic varieties that are often monstrous and made by such unnatural arts as selective breeding. Naturally enough, he compared species being naturally formed in the wild with natural variety formation in domestic species, and insisted that nothing like artificial selective breeding was going on in the wild and influencing natural species formation. His arriving at his selection analogy, near the end of 1838, entailed a direct reversal of this comparison and this contrast. So Darwin in no sense discovered species-making natural selection via analogical reasoning from variety-making artificial selection. The point bears emphasis, because so many popular and even scholarly histories do not appreciate it.

After Chapters 4–6 come two final chapters which put our analysis of Darwin's analogical argument and its prehistory to work in various ways. Chapter 7 tests our reconstruction against the views of four revisionist commentators on the argument. We conclude, unsurprisingly, that none of the revisionists' principal proposals are reconcilable with our own or preferable to them. But in showing why, in the light of Darwin's texts and contexts, these proposals are unacceptable, we take full advantage of the

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opportunities offered to explore a diverse set of subsidiary topics, from his use of imaginative conjectures in the *Origin* to the possibility that his distinction between artificial and natural selection encodes a distinctly Victorian vision of social hierarchy. Throughout we try to underscore the value of an awareness of the analogy-as-proportion tradition in interpreting Darwin's analogising, in the *Origin* and beyond.

Finally, in Chapter 8, we consider the bearing of our analysis on wider disagreements about and within Darwinian science. Once again we return to Aristotle, to emphasise that the Aristotelian character of Darwin's analogical argument in no way implies that Darwin's science was Aristotelian, and also because Aristotle provides a useful point of entry into complex questions about the relationship between 'art' and 'nature' in Western thought. Whether we consider the Aristotelian tradition on that topic, or the tradition associated with the Aristotelianism-rejecting Robert Boyle, or the Boyle-rejecting tradition begun by the Romantics, Darwin's analogical argument appears on inspection to be a poor fit for all of them. Taking seriously Darwin's taking seriously the breeders' art helps too, we suggest, when we ask about the relationship between his science and the capitalism of his time and place, which was far more agrarian than tends to be remembered. Turning from pre-Darwinian to post-Darwinian contexts, we look, later in the chapter, at how the analogy remained instructive for three major theorists in the Darwinian tradition: Francis Galton, Alfred Russel Wallace, and Sewall Wright.

It is no purpose of ours to insist that Darwin's analogical argument must remain scientifically important for all time. If we enable readers to understand more fully how Darwin understood the argument, and to appreciate how considerable was Darwin's skill in putting the argument as he did, that will be achievement enough. Nevertheless, so long as Wright's side of his famous debate with Ronald Fisher on natural selection attracts proponents, so long, we suggest, will Darwin's argument live.

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In our experience as readers, a book like ours benefits from an introduction which supplies not only a high-altitude overview but a fairly detailed inventory of the chapter contents, the better to help readers see the wood for the trees (to invoke another venerable analogy). We close this Introduction accordingly.

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Chapter 1: Analogy in Classical Greece

Analogy as proportion first played a decisive role in science in solving the problem presented to early Greek mathematics by incommensurable magnitudes. Pythagorean mathematics taught that the relative magnitude of any two lengths, A and B, could be commensurably specified by two whole numbers, *m* and *n*, such that, if A is extended to *m* times its length and B to *n* times its length, then the two extended lines will be equal. But pairs of lines were later found not meeting this specification; and Pythagoras's own triangle theorem – equating the square of the hypotenuse to the sum of the squares of the other two sides of a right-angled triangle – proved this possibility. The Pythagorean account of relative magnitude was duly replaced by an account, almost certainly due to Eudoxus, that covered both incommensurable and commensurable magnitudes. It did so by specifying when four magnitudes, A, B, C, D, are such that A divided by B equals C divided by D (A/B = C/D); and so, proportionally, when A is to B as C is to D (A:B::C:D).

Here A and B must be quantities of the same kind, distances travelled, say; but C and D could be of another kind, times taken perhaps. A four-term relation allowed comparison of quantities of different kinds; and Greek mathematics took the word ἀναλογία as the name for such a four-term relation. In the theory of similar triangles this form of reasoning provided a valid proof by analogy for the further properties two such triangles must share, by treating each as a model for the other. This Euclidean and Eudoxian geometry included an initial examination of analogical relations and modellings pertinent to all our chapters here.

Analogy as proportion, as, more literally, repeated ratio, was soon moved by Aristotle beyond its mathematical confinements to diverse unmathematical, empirical reasonings. While remaining committed to proportionality itself as essential to analogy, he freed it from the limitation that when A is to B as C is to D, A and B must be items of the same kind, and likewise for C and D even if A and C are unalike. With this limitation removed Aristotle can argue to and from fins being to fish as wings are to birds. He can formulate analogies where the two objects being compared are, as he says, remote. For objects close in character, direct comparisons will be appropriate, especially comparisons identifying shared properties; but for objects remote in character indirect relational comparisons will be more apt: scales being to fish as feathers are to birds, or fins being to water as wings are to air. Remote objects can be compared by identifying their relations to other remote objects, in later lingo to other 'relata'. There was

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a price, readily incurred, for this new Aristotelian freedom. With a four-term relation among quantities, knowing the values of any three allows, by what became called the rule of three, calculation of the fourth; but, if it is not known what is to fish as wings are to birds, these three known terms do not determine what this unknown fourth must be. Only empirical inquiry into fish structures and their functions can do so.

Such empirical relational comparisons play major roles in the comparative teleological anatomy of Aristotle's biological works. In these indirect comparisons, two animals as unalike as a bird and a fish can be models of each other.

Aristotle's biology was not called 'biology' and was not biology as Darwin's generation would know it. Aristotle's cosmology and his metaphysics, the foundations for his science of life, were no longer foundational for natural history and comparative anatomy more than two millennia on. But the legacy of his theory and practices of analogical comparisons endured. Darwin had to hand on HMS *Beagle* a brand-new little book – by the Oxonian John Duncan on *Analogies of Organised Beings* – a book acknowledging Edward Copleston and his former tutee Richard Whately as mentors who had enlightened the author about analogy, as proportional, relational likening, as taught by their own mentor Aristotle. Darwin's copy has no annotations so he is unlikely to have read it carefully and profitably.

Chapter 2: Analogy in the Background to the *Origin*

Mediaeval philosophers of all three leading Abrahamic faiths deployed Aristotle's teachings in their novel analogical comparisons of talk about God and about his creatures. The scholastic authors of the high middle ages, in their precision and sophistication, emulated their master, and in doing so gave 'analogy' new uses and meanings. Aristotle in presenting his account of analogy had talked of words 'being said in many ways', as in saying 'A is F' and 'B is F' when A and B have no common intrinsic property. Such cases include not only proportional analogies, but also cases where, for example, some diet for cows is said to be 'healthy', because it causes cows to be 'healthy' in what is today often called the 'focal meaning' of this word. Perhaps because they misread Aristotle, the school men called all these cases instances of 'analogy', while retaining the contrast between analogy and simple similitude. With their preoccupation with analogy's implications for such ontological and linguistic questions, they had little interest in argument by analogy. So, in preparing historiographically for

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our chapters on Darwin's *Origin,* we write only very briefly about what Aristotle's mediaeval followers did with his legacy as analyst of analogy.

The precision and sophistication of the scholastics was not emulated by Renaissance and Enlightenment authors in the sixteenth and seventeenth centuries, in their revivals of Epicurean, Stoic and Platonic alternatives to Aristotle's legacies for philosophy and for the sciences. Today's historical dictionaries for vernacular European languages, like the encyclopaedias from those centuries, confirm that 'analogy' and its cognates became used in diverse and casual ways, acquiring many uncoordinated meanings with little in common except some association with 'similarity'. These undisciplined discursive habits extended into the early eighteenth-century decades, when the battle between the ancients and the moderns turned in favour of authors declining deference to Greek and Roman antiquity. Within the norms of his time, Joseph Butler countered deism, in his 1736 book on the *Analogy of Religion, Natural and Revealed, to the Constitution and Course of Nature,* with no explication for the leading term in his title.

As we have already noted, an enduring alternative to the Aristotelian view of analogy as relational comparison traces to Thomas Reid, over two decades before Darwin's birth, and is still prominent today. And by the beginning of Darwin's century, there were three influential clarifications of analogical reasoning. Kant in Germany and Copleston in England independently returned to Aristotelian analogy as proportion, making no concession to the Scotsman Reid's recent version of analogy as similitude. Kant drew mainly on Aristotle himself. With his concern to demarcate cognitive roles for reason and experience, Kant emphasised the differences between analogies constituting a priori mathematical knowledge, and those contributing to empirical knowledge a posteriori; and so he dwelled especially on analogies, prominent in the natural sciences, asserting sameness of causal relations and supporting inferences from the known to the unknown consequences of those causal relations.

In England, at Oxford, Copleston saw himself as in descent from William King, an Irish Anglican bishop who, along with Peter Browne and the more famous George Berkeley, had discussed, early in the eighteenth century, the implications of analogy as proportionality for venerable questions concerning human knowledge of God. In the late 1820s, Whately, another Oxonian affirming his debts to King and soon to be an Anglican Archbishop in Ireland, gave analogy as proportion a place in both his logic and his rhetoric texts, just as Aristotle had. Well into Darwin's adult life, Whately stayed resolutely committed to the Aristotelian understanding of analogy; while John Stuart Mill carefully

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distinguished Aristotelian and Reidian arguments by analogy, regarding both as legitimate, although very different, forms of argument.

Darwin was sent to Cambridge by a cynical unbelieving father who thought a career as a Church of England priest would suit his son better than an earlier curricular choice, medicine, had done. Convinced that he was himself a sufficiently believing Christian this student son studied carefully two books by Archdeacon William Paley, one on revealed and the other on natural theology. Later, when reflecting on these two theologies, he was indebted to Paley's typically eighteenth-century evidentialist view of religious belief. On analogy, Paley had no sustained stance to teach. His arguments to divine intelligent design in nature do not exemplify any analogical forms of reasoning, whether Aristotelian or Reidian. Nor were Darwin's analogical reasoning practices instructed by any reading in any writings on analogy in general; but our readings of Darwin can be instructed by those writings even if his writings were not.

Chapter 3: Darwin's Analogical Theorising before the *Origin*

Darwin arrived at his selection analogy very late in 1838. Nearly four years earlier he had begun his first sustained proportional, analogical reasoning on behalf of a causal–explanatory theory. This theorising, about species mortality and so species extinctions, is the single most instructive precedent for Darwin's analogical reasoning about natural selection.

Darwin opened reflections on species extinctions, in February 1835 when still in South America, by admitting of an 'analogy' that it was a 'false one', but then adding a 'but' and defending it. With apple trees, artificial grafting could vastly extend the life of one bud but, horticultural lore agreed, only extend it limitedly as if the successive trees propagated by repeated grafted cuttings were all parts of one tree. So, Darwin argued, the lifetime of a mastodon species could be extended vastly but limitedly by natural sexual reproduction.

In spring 1837 this analogy of Darwin's, although not claimed to be 'close', is no longer deemed false. He has now developed an explicit foundation for it: all generation, sexual and asexual, natural and artificial, extends life by reiterated divisions of individuals beginning with an initial individual containing a limited, finite quantity of extendible life. So, natural sexual generation is to the extending and ending of an animal species as artificial grafting is to the extending and ending of a grafted plant succession. The common causal relation of limited generational division has a common causal consequence: the limitation of extended life.

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Darwin's main mentoring as a theorist of generation was at Edinburgh before going to Cambridge. On the voyage, he drew on Lyell's respectful review and rejection of inherent species mortality theorising in explaining species extinctions. There is no reason to think that Darwin's development of his analogy drew directly on any general analyses of analogical reasoning. And it was to be likewise with his first analogical reasonings about natural selection.

Reflecting on Malthus in late September 1838, Darwin took the high potential rates of animal population increase to vindicate Lyell's view of species extinctions as due, not to any inherent species mortality, but to terminal competitive imbalances caused by very slight changes in local conditions. So much for losing species. Darwin says that the 'final cause' of population pressure, its good consequence, presumptively Divinely intended, is to 'sort out', discriminatingly retain, in winning species, adaptive structures fitted to changing conditions. But more than two months will pass before he likens this sorting to artificial selection, and drops his longstanding contrast between species formation in the wild and the making of domesticated varieties by selective breeding.

Around 30 November, Darwin declared, in unusually triumphant mode, that three numbered principles will account for everything: a principle of heredity, of variation and of superfecundity. These three principles do indeed constitute what he will eventually, in the early 1840s, call his theory of 'natural selection'; but it cannot be called this yet because there is still no selection analogy. Within days comes the first talk of nature's picking or selection, with immediate emphasis on this selection by nature being far more powerful than artificial selection. By mid-March 1839, the reversal concerning varieties is explicitly decisive for Darwin's plans for public argument: some domestic varieties are formed by natural adaptations to local conditions, but greyhounds, pouter pigeons and others are made by the arts of crossing and selection. Hence, next, this question: does nature have 'any process analogous'? And hence Darwin's resolving to answer by introducing his theory, later texts showing that he would here invoke superfecundity as causing the struggle for existence and its natural selective breeding consequences.

Darwin had not reasoned thus: domestic varieties are made by selective breeding; wild varieties are like domestic varieties; like effects have like causes; so wild varieties are made by something like selective breeding in the wild. Had he done so, the existence of selection in the wild would have been inferred from its existence on the farm. No, Darwin reasoned that, owing to the struggle for survival in the wild, sorting exists in the wild and

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causes adaptive change; and owing to stockbreeding practices there is selective breeding on farms causing diversification of domestic varieties; and (on subsequent reflection), the discriminating sorting effects of the wild struggle are seen to resemble the effects of the breeders' art. Hence it is not true (as he'd previously thought) that there is nothing like selection going on in the wild. Here the existence of selection in the wild is inferred not from the existence of selection on the farm, but from the consequences of the existence of the struggle for survival in the wild; the struggle, in its selective actions and their consequences, is then causally to wild animals as the stockbreeder is causally to farm animals. Same causal relation and same consequences. Thus did Darwin arrive at this four-term causal–relational comparison, this analogical proportion.

The construction of the theory of natural selection and its analogical articulation had resulted from a complex series of steps in nearly half a year from September 1838 to March 1839; steps that, with allowable hindsight, can be read as eventually, gradually bringing him to this result. In 1842 Darwin wrote out a brief rough sketch of his theorising. It would be the textual ancestor to the book-length draft essay of 1844; and so too to the very big book he was calling *Natural Selection* and composing, in 1858, when Wallace's letter and essay prompted him to prepare the *Origin* as an abstract. In these years after 1839 and before 1859, Darwin had various new unpublished thoughts about natural selection. But the theory was never modified, then, or indeed after 1859, in any ways requiring modifications to the selection analogy.

Chapter 4: The 'One Long Argument' of the *Origin*

The *Origin's* first edition has an introduction on how Darwin came to write it and what its fourteen chapters are about. Opening the final chapter he calls the book 'one long argument', and then recalls the argument's main elements, before closing with their implications for future science.

Within the thirteen chapters before the final one, the relationship between the initial four and last five is decisive for the structuring of the long argument; for the argument makes three evidential cases for natural selection: the case for the existence of this cause, and the case for its power to form and adaptively diversify species (I–IV), and the case for its having been responsible for the forming of extant and extinct species (IX–XIII). Existence, adequacy and responsibility. It is, it could and it did. In that order, because only an existing cause could be adequate, and only an existing and adequate cause could have been responsible. Hence, the initial

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four chapters marshal evidence for existence and adequacy, and the last five for responsibility. Hence, in the intervening four chapters (V–VIII), one chapter complements the book's opening two on variation on the farm and in the wild, and three then counter objections to the adequacy case made in chapter four. Chapter IX is sometimes associated by Darwin with this sequence of intervening chapters. But it properly belongs with the later sequence in countering in advance objections to the responsibility case.

The *Origin* offers scant explicit guidance on how the long argument is conducted but the unpublished drafts help. For the 1842 *Sketch* and 1844 *Essay* are conformed more discernibly to the vera causa (true cause) evidential ideal. The ideal had had its canonical formulation in Thomas Reid's brief explication of a Newtonian methodological dictum, but Reid did not associate it with his view of analogy. Among the scientists most respected by Darwin, the ideal was upheld by Lyell and by Lyell's friend and geological ally, the physicist and astronomer John Herschel; and it was later rejected by Lyell's critic and Herschel's friend, the polymath Whewell. The agreement of the two Reidians, Lyell and Herschel, undoubtedly influenced the young Darwin but precisely when and how is not known.

A traditional requirement for any causal–explanatory hypothesis was that the cause it invokes be evidenced as capable of producing the kinds and sizes of effects it is to explain. Further, a good hypothesis explains many different facts about those effects. Such explanatory virtue is evidence for the responsibility of the cause for the effects and so for its existence; but, because this evidence for its existence is not independent of these facts, the hypothesis is deemed to be conjectural, speculative and the cause hypothetical. By contrast a vera causa is a cause that has its existence also evidenced independently by facts other than those it is to explain. So, to show that some causal–explanatory theory is no mere hypothesis but a vera causa theory and hence inductive, not conjectural, the two requirements met by any good hypothesis must be met and a third also: independent evidence that the cause is real, true, exists and is known. Darwin's theory is that natural selection with arboriform descents is responsible: it did it. This is the punchline for the whole book, the conclusion of its long argument. By arguing for the existence and adequacy of this cause, the first four chapters enable those later five (IX–XIII) to argue for this conclusion, and so for this theory.

The selection analogy has no role in the case for the existence of hereditary variation, nor in the case for the existence of natural selection. The opening chapter gives evidence for the existence of hereditary

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variation under domestication, and the second chapter argues from this to the existence of such variation in the wild. The causes of all hereditary variation are the same: changes in conditions, in soil, climate, food and so on. Such changes are known to be effective under domestication. Geology, Lyell's geology, shows such changes going on everywhere and always in untamed nature, and they can be inferred to have similar effects in causing hereditary variation albeit less abundantly than on farms and in gardens. The existence of deliberate selective breeding on farms and in gardens has been widespread in recent decades. But there is no inferring from this that there exists selective breeding in nature. As argued in the third and fourth chapters, the existence of natural selection can be inferred from excessive animal and plant fertility, and the consequent struggle to survive and reproduce in the wild. For in this struggle there will be consistent, persistent and comprehensive discrimination among hereditary variants, favouring and so preserving advantageous variants in successive generations.

In this discrimination the struggle is acting as a stockbreeder does in forming and diversifying animal varieties. But with two differences: whereas the stockbreeder forms varieties fitted to their uses or fancies, the struggle forms varieties adapted to the animals' and plants' own ends of survival and reproduction; and, second, while these effects of the struggle are the same in kind as the effects of the stockbreeder's artificial selection, the effects wrought in the wild can be vastly greater in degree, including the transforming of wild varieties into new species; for varieties and species differ only in degree not in kind, varieties being incipient species, and species well-marked varieties. So, over eons, selection in the wild can cause the adaptive diversification of the entire tree of life. The selection analogy here supports an argument a fortiori, from the greater strength of natural compared with artificial selection. The fourth chapter, and the case for the adequacy of natural selection, can then end with the principle of divergence. Since structural and functional specialisation is usually advantageous in life's struggle, over long ages natural selection causes, reliably if not invariably, branching and re-branching structural and functional divergences in favouring diverse adaptive specialisations, with more specialised species winning out over the less specialised which become extinct. Specialisation being a criterion for progress, this adaptive tendency is progressive.

These – the conclusions in Darwin's fourth chapter, about the powers and tendencies of natural selection in divergent branching modifications of common ancestral inheritances – are conclusions about the tree of life and

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natural selection, and so about the implications of each big idea for the articulation of the other. First fully integrated in this most crucial chapter, the two big ideas remain so for the rest of the book: being defended in the middle four chapters, and deployed in the five following them in formulating explanations for many kinds of geological, geographical and morphological facts about extinct and extant species. The conclusions of the fourth chapter are deployed in these explanatory tasks because they have established what consequences branching natural selection, the cause, can have, and therefore what branching natural selection, the theory, can explain and how. The special conclusions of the arguments from the selection analogy are then decisive for the long argument of the whole book, a long argument conformed to the Reidian vera causa evidential ideal, not however to Reidian analogy as similitude, but to Aristotelian analogy as proportion.

Chapter 5: An Analysis of Darwin's Argument by Analogy

In modern times, the reputation of analogy has suffered from associations with unfashionable mediaeval scholastic theological apologetics, and from confusion about how analogical reasonings are formally structured and so logically assessed. With Mill, if not with Copleston and Whately, those old associations fade away; but there remains today a need for elementary formal precision.

With Aristotelian analogy as proportion the argument from a four-term relational comparison is an argument from one or more premises about an analogical model, to one or more conclusions about an analogical target. Suppose a situation or object or state of affairs, M, is an analogical model of target situation T. If M is F and being F is invariant under the analogy, and so inferably transferable from M to T, then T is F. An oven baking dough is a model for the sun shining on mud. The oven is F, is drying and so hardening what it bakes. Drying with hardening (F) is inferably transferable from model to target, therefore the sun is F, is drying and hardening what it shines on. Here A (the oven) having relation R (heating) to B (the dough) is a model for the target, C (the sun) having the same relation R to D (the mud). The model is what is learned from and the target is what is learned about. The modelling scheme can be expanded by adding that the model M is G and that M's being G suffices for M's being F; and adding that T is G. Then it follows that T is F. The oven being hot (G) suffices for the drying with hardening (F); the sun is hot (is G); so it dries and hardens (F) the mud. This is valid analogy, and suggestive

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justification for saying that the sun bakes the mud, and so for talking metaphorically as if a culinary art is practised by solar nature. Reasoning from the oven's being hot is meeting Mill's requirement that any reasoning from a proportional analogy should be supported by a material circumstance; by a circumstance relevant to the model having what is invariant under the inferential transfer. Here there is causal relevance; for this circumstance, the heating, is common to model and target, and has as a causal consequence the invariant, transferable feature of the model, the drying with hardening.

As with many argument forms, so with reasoning from analogical modelling: simple schemata and homely examples can make the whole business look commonsensical, but hardly capable of instructive scientific sophistication. And there are indeed only two simply specifiable requirements for validity in an argument from a four-term relational comparison asserting that A is related to B as C is to D. For to infer validly, from this comparison, that D shares some feature known to be possessed by B, it is necessary that the common relation does truly hold in both cases; and that, in conformity with the material circumstance requirement, in both it does truly have the same consequences. Same relation and same consequences of same relation: those are the essentials. Told by Darwin that the stockbreeder is related to the animals on the farm as the struggle for existence is to those in the wild, his readers have to ask if these relations and their consequences are truly the same, or at least sufficiently relevantly similar to support the conclusions Darwin is drawing from the four-term comparison.

Answering these questions is often far from easy, thanks to Darwin's concern with detailed, actual exemplifications and with pre-emptive counterings of objections to his premises and conclusions, all in prose rarely deft and lucid. Many exegetical difficulties diminish if we separate, as Darwin does not, two stages in his reasoning from premises about his analogical model, artificial selection on the farm, to conclusions about his analogical target, natural selection in the wild. The first stage argues that just as artificial selection forms new domestic varieties, so natural selection can form new wild varieties. The second stage, building on the first, argues that natural selection, unlike artificial selection, can form and diversify without limit new species, and so species of new genera, families, classes and so on. In both stages the material circumstance requirement is met by establishing that, in both artificial and natural selection, there is consistent and persistent favouring of some hereditary variants over others throughout successive generations. So, in both stages, artificial and natural selection are being compared qualitatively as causal processes of the same kind. But in

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the second stage they are also being contrasted quantitatively as causal processes differing vastly in degree. A brand of bitter ale used to be advertised as like beer but more so. Darwin's natural selection is like artificial selective breeding but more so.

The greater power of natural selection is manifest when considering the more precise, comprehensive and prolonged discriminations among hereditary variants effected by the struggle for existence: the struggle due to the tendency of reproductive multiplication to produce more offspring than can be sustained by the limited resources, of food especially, that sustained the parents' generation. Arguments from this greater power are arguments a fortiori. Darwin's a fortiori arguments are not arguments making stronger the reason for accepting some conclusion; they are arguments from the greater strength of one cause compared with another, and so to the greater extent of one lot of effects over another.

A fundamental feature of analogical proportion, alternation, is exploited here. 10 is to 5 as 2 is to 1 can be validly alternated to 10 is to 2 as 5 is to 1. Likewise, if artificial selection is to the making of domestic varieties as natural selection is to the forming of wild varieties, then, by alternation, what the stockbreeding community does is to nature's workings as the making of domestic varieties is to the forming of wild ones. With this alternation, a vast scaling up of farm life can be a model for the alternated analogy's target: the whole living world.

To summarise, natural selection is to the effects of natural selection as artificial selection is to the effects of artificial selection. Therefore, natural selection is to artificial selection as the effects of natural selection are to the effects of artificial selection – the more powerful the cause, the more powerful the effect, and the achievements of natural selection may far surpass those of artificial selection.

Chapter 6: Darwin's Use of Metaphor in the *Origin*

If analogy needs rescuing from unfashionable associations, metaphor needs rescuing from fashionable ones, especially from recent if now passé vogues for Nietzschean one liners about truth being a mobile army of metaphors. In understanding Darwin's uses of metaphor, rescuing can begin with Aristotle's views on what analogy and metaphor can do for each another.

If real, analogical relations are in the world. If meaningful, metaphors are effective practices within language. Metaphors can suggest analogies; and analogies can support metaphors; and, as Aristotle taught, proportional analogies are especially good at doing so.

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An analogy can support more than one metaphor. By elaborating the relational comparison the analogy is making, it can support a metaphor's extension in further successor metaphors. An initial comparison of Shakespeare's Antony with the Sun can support talking metaphorically of his death as a sunset. With additional analogical comparisons between this death and a sunset, further reiterated supportings are possible. With artificial selection as his analogical model for natural selection, Darwin can talk metaphorically about nature's discriminating among animals in the wild, as if he were talking about a farmer discriminating among his livestock.

In supporting metaphors with analogy Darwin, man of science, had to be constrained in two ways not expected of the poet Shakespeare composing his play. Darwin's metaphors had to be amenable to literal, if cumbersome, paraphrase informed by the supporting analogy; and they had to contribute to the argument of his book. Many of the Bard's metaphors resist literal paraphrase; and while his play may present arguments, he has not composed it as one long argument for a causal–explanatory theory.

Throughout the *Origin*, Darwin is deploying metaphors as convenient and vivid shorthand; and he is elaborating metaphors in making extended comparisons between life in the wild and on the farm, life in the short run of the present and long run of the past.

His metaphors contribute also to concept formation. The physicists of his day were likewise giving words new meanings by giving them new metaphorical uses to meet needs for new concepts. Traditionally work was what a human or a horse did in tilling a field. But the word 'work' could be used metaphorically of what a machine did in a factory or on a railroad track; and here the work of any machine in a specified time could be quantified as equivalent to the lifting of a standard weight through a standard height; and this physicists' concept of work could feature quite abstractly in developing thermodynamical theory. The word would keep its workaday uses and meaning, while theorists of thermodynamics would no longer align their term and its meaning, their concept, with toiling and tilling talk.

Darwin's concepts were not as quantitative and abstract as the physicists'. His selection and struggle talk stayed closer to pub and street talk than theirs did. His selection and his struggle metaphors contributed to the formation of his concepts of natural selection and of the struggle for existence, in ways making their phrasings open to varied interpretations and persuasive uses leading sometimes to confusion and dispute among his readers. His own uses of the phrase 'natural selection' may take both words metaphorically rather than literally. But sometimes the first word is taken

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literally and the second metaphorically, or indeed vice versa, while again both words may be taken literally. In using metaphors Darwin was obviously not an innovator, but his uses for metaphors were not casual and conversational. Many of his most sustained metaphors are in his book because they are prompting suggestively his deployments of his analogical modelling which, in return, is grounding and supporting those metaphors.

Chapter 7: Rebuttals of the Revisionists

Until recently there was consensus that Darwin's *Origin* argues analogically for the theory of natural selection, although there was no agreement about how the analogical reasoning goes. Lately this consensus has been challenged by several revisionists who, while disagreeing among themselves as detailed earlier, all see analogy contributing little to Darwin's long argument. On our reading of the *Origin's* long argument, Darwin is integrating throughout the Reidian vera causa ideal and the un-Reidian, Aristotelian norm of analogy as proportion. The four revisionist views rule out any such interpretation, which is why we have weighed them carefully, before concluding that they are not established by textual evidence.

James Lennox accepts that Darwin conformed his theorising to the vera causa ideal, but proposes that he met the ideal's adequacy requirement not through analogical comparing of artificial and natural selection, but through imaginary illustrations of natural selection called by Lennox 'Darwinian thought experiments'. In Lennox's analysis, rejection of the analogical interpretation is implicit. Richard Richards, Peter Gildenhuys and D. Graham Burnett have rejected it explicitly but without agreeing on where it goes wrong and what should replace it. Like Lennox, Richards sees Darwin as meeting the adequacy requirement by appealing not to any analogy between artificial and natural selection but to something else: not thought experiments, however, but real experiments, accidentally conducted when selectively bred domestic animals have gone feral. For Richards, Darwin made use of the selection analogy only as a heuristic guide to how natural selection works. Gildenhuys, even more radically, thinks the vera causa ideal irrelevant and denies that Darwin recognised analogous forms of selection. He presents Darwin as using a selection analogy only in establishing a completely general account of selection wherever it is found, and however much its various forms seem to differ. Burnett is no less radical in a different direction, stressing Darwin's appeals to diverse forms of selection. Darwin's use of them to fill the gap between artificial and natural selection results in a spectrum so continuous, Burnett

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says, that it subverts any analogical argument. Far from this subversion weakening Darwin's case for natural selection, however, it is, in Burnett's view, this very collapsing of analogy into identity that gives the long argument its strength.

Sometimes exegetical disagreement has to be unequivocally articulated if it is to be honestly and respectfully expressed. Our disagreements with these four revisionist views bar any compromise or assimilation. For, like all earlier interpretations of Darwin's reasoning in the *Origin*, none of the recent revisionist proposals takes any sustained account of the Aristotelian tradition of analogy as proportion, whereas our reading of Darwin brings that tradition to the interpretation of the overall structure and the detailed content of Darwin's long argument.

Chapter 8: Wider Issues Concerning Darwinian Science

Placing Darwin in the long run of Western thought concerning relations between art and nature requires at least two contrasts. The art of selective breeding is not like the art of a doctor doctoring himself; but, for Aristotle, thinking of an acorn artfully turning itself into an oak tree, such a doctor is what nature is like. Nor is selective breeding like the art of a seventeenth-century Boylean or nineteenth-century Paleyan watch maker, who makes a small mass of passive, inert metallic matter into an intricate working machine that this matter could never turn itself into. The selective breeder's mindful art works with the active powers of reproduction and hereditary variation; so too does the mindless, artless but artlike, natural struggle for existence as the selector in the wild.

Stockbreeders make and improve breeds, varieties, by sustained selecting among individuals, selecting which eventually results in better individual living machines later. But this improving of the individuals is not done by going to work on each individual as an individual doctor doctors himself, or as a watchmaker makes one watch at a time, but by going to work on a flock, a herd, or an orchard over generations.

So, there is no significant likeness here to the inventing and improving of industrial machines for machino-facturing capitalism; but there are manifest alignments with agrarian capitalism's profitable improvements of animal livestock and crop plants by selective breeding. Nature's selector, the struggle, is a Malthusian consequence of reproductive fertility outrunning food resources; and land use for food production was the link between Malthus on population and Malthus as defender, against the machino-facturing interests, of Corn Laws, and as defender in economic

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theory of earlier French physiocratic privileging of agrarian capital over all other capital. So, Darwin's selection analogy is not descended from a venerable tough-minded Cartesian mechanist metaphysics newly inspired by a youthful English machinist industrial capitalism. Is it then to be read as grounded in a tender-minded, pantheist, even pananimist view of nature owing to Darwin's debts to Humboldt and so to expressivist, aestheticist, idealist German Romanticism? Hardly. Darwin in the 1830s is no atheist but no pantheist either. Nor, for Darwin, is all nature ensouled. Again, German romantics, Schelling, the brothers Schlegel and their like, privileged art over science and religion in their views of man and of nature, but not art as craft but art as poetic, creative expression of human selves; art as Beethoven or Schiller not art as Bakewell the Leicestershire stockbreeder known as the man who invented sheep.

Placing Darwin in a tradition of analogy as proportionality requires seeing how he could be in this tradition, and yet far from perpetuating any Greek traditions in metaphysics and cosmology, whether Epicurean, Platonic, Stoic, or indeed Aristotelian. Turning from the long to the short run, it means seeing how he could be – like his main mentors as a scientific theorist, Lyell and Grant – predominantly Scottish and French in his scientific culture and therefore only very slightly Germanic and far from predominantly English. The Aristotelian tradition of analogical–proportional reasoning had no inherent connection with one view of man and nature rather than another. The content of Darwin's selection analogy has its historical sources, but that content is no more owed to the German Kant or Scottish Mill than it is to the Greek Aristotle, even though the analogy's structure and function does align him with their shared proportionality view of analogy.

Aristotle on analogy, Reid on true causes and Darwin's agrarian modelling for life in the wild are directly relevant to evolutionary biology in our time. What is arguably still the most influential theory of evolutionary genetics, Sewall Wright's shifting balance theory, was developed and defended by him as modelling evolution on artificial breeding practices, including especially the carefully recorded breeding practices of shorthorn cattle farmers in north-eastern England in Darwin's century. Wright and fellow founders of mathematical population genetics, Fisher and Haldane, brought statistical theory to their modellings of evolutionary processes, but statistics as analyses of causal processes – selection, inbreeding, mutation, random drift and the rest – not as mathematical replacements for causal analyses. Darwin and his recent scientific descendants, for all that they are obviously modern in attitudes and achievements, nevertheless draw in their work on traditions going back centuries, even millennia.

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