Charles Darwin's
Multimodal Scientific Invention

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Chapter One: Introduction

Since the rhetoric of science first became a discrete research tradition, scholars in this area have paid considerable attention to rhetorical invention in science. This interest has stemmed from a number of scholarly and pedagogical goals, has employed a variety of methods, and has been applied to a number of different sorts of scientific discourse. It has also provided valuable insights into how scientific argument works, how scientific texts are generated, and even how scientists develop theoretical innovations. As valuable and varied as this scholarship has been, however, it has tended to relate solely to scientific language, and not to deal very extensively with other modalities like diagrams, tables, thought experiments, or mathematical expressions. Gross, Harmon, and Reidy (2002) note the centrality of multimodality in twentieth century scientific communication: "it is no longer sufficient to string together an array of facts describing what the observer did, saw, or measured," they argue; "one must argue them into place by pulling together a multimedia collage of words and pictures exhibiting methods used to acquire facts, new facts derived from those methods, theoretical explanations for the facts in the light of past published research, and visual evidence in support of the facts and explanations" (187). In short, multimodality is essential to contemporary scientific practice.[1] Moreover, this multimodality has, in various forms and to various extents, been essential to scientific practice

[1] See, e.g., Latour and Woolgar (1986), Rowley-Jolivet (2000), Wickman (2014), and Walsh and Ross (2015).

for centuries.[2] It is somewhat surprising, then, how little of the scholarship on scientific invention examines the interactions among representational modalities.[3]

I address this scholarly gap in this dissertation by investigating multimodal aspects of scientific invention, using the notebooks, manuscripts, and published writings of Charles Darwin as the base of my analysis. In this chapter, I will present my method for analyzing Darwin's scientific invention, comparing its purpose and utility with approaches previously used to study invention. In each of my subsequent chapters, I use this method to analyze one particular episode of Darwin's multimodal inventional practice.

Approaches to the Study of Scientific Invention

Rhetorical scholarship on scientific invention has employed various rhetorical concepts, analytical approaches, and objects of study. Broadly speaking, however, this scholarship may be divided into three basic types. First, scholars have attempted to develop exhaustive inventories of the inventional choices available to scientific rhetors—that is, inventories of available topoi. Second, scholars have attended in particular to one inventional practice: the use of analogy. Third, scholars have focused upon one particular episode of scientific invention, following its particular complexities in detail through time.

Topical approaches to scientific invention attempt to develop a comprehensive inventory of the inventional choices available to scientific rhetors. Lawrence Prelli (1990), for example, constructs a comprehensive system of stases and topoi which govern the generation and

[2] See, e.g., Rudwick (1976), Gooding (2006), Jack (2009), and Gross and Harmon (2014).

[3] There are, of course, exceptions to this general neglect which I will describe in detail in the opening sections of chapters three and four. These exceptions, however, are by no means numerous.

evaluation of scientific claims. By producing this system, he hopes to represent something which he variously calls "the rhetorical logic of science," "the prevailing rhetorical logic of scientific argumentation," and "The logic of rhetorical invention in science" (260, 265). Similarly, Lynda Walsh (2010) sees topoi as "shared communal strategies for ordering and investigating experience" (125). By developing a list of topoi employed in scientific research articles, and by investigating how these are employed in the different sections of scientific research articles, she hopes to give analysts insight into the underlying structure of scientific argumentation: "studying how topoi sequence into larger signatures, and how those larger signatures might differ across species of STEM discourse and develop over time, can illuminate the communal organisms that are STEM fields" (147).[4]

Topical approaches demonstrate that many of the strategies which scientists employ in legitimizing and evaluating knowledge claims have been studied by rhetoricians for centuries. They also make possible a fine-scale examination of particular acts of scientific argumentation relative to other available rhetorical choices. Unfortunately, the insights provided by topical invention come at a rather steep price: one must first develop at least a provisional system of all of the inventional choices available to scientific rhetors. Gaonkar (1990) points to the complexity of this process in Prelli's book: "Prelli's exposition of the method in the second part of the book turns into an endlessly complex affair as he offers a threefold characterization of rhetorical ends, a four-by-four *stasis* schema for analyzing issues, and a list of 22 possible and recurrent lines of arguments (*topoi*)" (286). To develop her own topical inventory, Walsh analyzes18 research

[4] An important difference between Walsh's topical approach and Prelli's earlier scheme is that Walsh sees topoi more broadly, as "pervasive dynamic and cognitive strategies—linking people, texts, and experiences—that engage particular rhetorical situations" (122). Thus, the topos Appearance versus Reality can be used to argue for a scientific explanation which does not at first sight appear plausible; it may also, however, provide a guide to investigative methodology (e.g., encouraging a scientist to probe behind what seems obvious about an empirical phenomenon) and even as an instantiation of a particular scientific norm or value, such as scientific skepticism (127-28, 130).

articles published in six different scientific journals, employing existing topical inventories by Aristotle, Perelman and Olbrechts-Tyteca (1971), and Prelli (1990) in her analysis. The result of this labor is a list of thirty distinct topoi, each of which must be named and defined in plausible and analytically useful ways. Moreover, this is only a first draft; further reliability would still need to be generated for this list either by "intensive norming of coreaders" or by computerized corpus analysis (148). The vast labor required for the topical approach thus presents a practical obstacle, at least for now, to its widespread use in the rhetorical criticism of scientific discourse.

If the results of this labor were applicable to any scientific argumentation whatsoever, from any discipline and any time period, the work involved would be very much worth the effort. However, there is no guarantee that topoi used by one disciplinary community will all be shared by another, and even the topoi employed within a given community are likely to change over time (Prelli 1990, 78; Warnick 2000). Studying scientific invention in the mid-nineteenth century is not the same as studying scientific invention today, and there are likely to be important differences between, say, how physicists and biologists produce and evaluate knowledge claims even at one particular point in time. Because of the likely variety across times, disciplines, and scientific genres, the challenges involved in topical approaches begin to appear prohibitive. Thus, though topical methods hold great promise when an inventional scheme has already been developed at a given time, for a given discipline, and/or for a given scientific genre, the effort necessary to develop a topical scheme, as well as the scheme's questionable applicability beyond the domain of scientific argument used to generate it, place severe limits on the practicality and breadth of this approach to invention.

The second common approach to scientific invention concentrates on one particular inventional tool: analogy. Analogical argumentation has interested rhetoricians since the classical period, but the approaches of Joseph Little (2000, 2008) and Heather Brodie Graves (2005) provide important innovations. First, analogical invention is examined, not just in relation to argumentation, but also in relation to the generation of theoretical innovation in science. Thus, in *Rhetoric in(to) Science,* Graves provides an ethnographic study of physicists which shows them routinely using analogy to generate new insights into natural phenomena. Similarly, in a pair of articles, Little shows physicists using analogy to develop, not just novel argumentation, but also new models of the inner workings of the atom.

Second, analogies are treated, not as indivisible, monolithic units, but as things of parts. Rather than treating an analogy as a single item, Little and Graves examine analogy at the level of the individual mappings which make up the analogy. Relying on a model of analogy developed by cognitive psychologist Derdre Gentner and her colleagues,[5] Little and Graves both treat analogies as systems of mappings between domains—the "base" and the "target." By treating each mapping individually, a more fine-scale analysis of analogical invention is possible. Thus, Little examines how the physicist Hantaro Nagaoka's analogy maps the structure of the atom to the structure of Saturn's rings. Rather than treating this analogy as a monolithic item, Little instead treats particular analogical mappings as the units of analysis: electrons revolve around a positively charged central nucleus just as the particles of Saturn's rings revolve around Saturn, for example. By treating these analogical mappings in such detail, Little can show ways in which accepting the analogy forced Nagaoka to accept certain consequences of his model on pain of contradiction—for example, unlike other physicists of his time, Nagaoka was constrained by the mappings of his analogy to assume a corpuscular nature for electricity (Little 2000, 83).

[5] See, e.g., Gentner 1983 and Gentner et al. 2001.

A third innovation of recent analogical approaches to invention is that analogy is treated as an inventional process that unfolds over time. This feature is particularly evident in Little's (2008) discussions of the physicist George Gamow. Little shows how Gamow derived his liquid drop model of the atomic nucleus gradually. This inventional process culminated in the mathematization of the model, a mathematization which Little depicts as intrinsically derived from the analogy (2008, 234-35). Thus, the analogical approaches of Graves and Little differ from classical studies of analogical invention in that they 1) involve the creation of theoretical innovation as well as rhetorical innovation, 2) analyze the individual mappings which comprise an analogy, and 3) trace the generation and evolution of such analogical mappings through time.

Analogical approaches developed from Gentner's structure-mapping model of analogy have already shown great promise in the analysis of scientific invention. Unlike topical approaches, which deal only with the invention of scientific argumentation, the approaches of Little and Graves show that analogy provides epistemic value to scientific investigation. The development of a scientific explanation and the development of supporting argumentation for that explanation may be examined together, using the same analytical framework. Analogical approaches also, unlike topical approaches, allow scholars in rhetoric to examine the diachronic *process* of scientific invention, rather than dealing only with the finished choices found in published scientific argument.

The most obvious drawback to the analogical approach, however, is its narrowness: no episode of scientific invention is ever solely analogical, and there are many other ways to generate theoretical and rhetorical innovation besides analogy. Moreover, since analogical mappings are the unit of analysis for this approach, very detailed analyses of a scientist's conceptual and argumentative innovations are possible; however, the symbolic instantiation of the theory and argumentation are typically not treated in detail at all. Decisions about how to phrase an argument or a model or about which particular visual or verbal presentations to employ are seldom visible within this type of analysis. Thus, though the analogical approaches of Graves and Little provide us insight into a particular inventional practice and allow us to see the epistemic significance of that practice, there are inventional strategies and aspects which these approaches cannot easily address.

The final approach to scientific invention is the process approach exemplified by Gross (1990), Campbell (1990a and 1990b), and Crick (2005). Rather, than concentrating on a particular sort of inventional strategy, like topos or analogy, these scholars concentrate on a particular episode of scientific invention, following it through time in all its complexity. For all three scholars, the episode of scientific invention is the same: Charles Darwin's development of his theory of evolution, as shown in the so-called transmutation (i.e., evolution) notebooks.[6] Each of these analyses begins from a particular theoretical focus which guides the interpretation of invention in these notebooks: Gross analyzes Darwinian invention in the notebooks in terms of a move from self-persuasion to the persuasion of scientific audiences, Campbell analyzes it as the development of a particular image or metaphor subsequently elaborated argumentatively, and Crick analyzes it in terms of the internalization of other scientists' perspectives and the manipulation of these perspectives into internalized, perspective-taking dialogues. Thus, rather than starting from a well-established rhetorical concept like topos or analogy, the interpretive handle by which these scholars examine scientific invention is suggested by the particular episode being investigated.

[6] In Darwin's time, the word "evolution" was used to refer to the development of an organism across its lifespan; what we today call "evolutionism" was at that time called "transformism" or "transmutationism" (Gould 1977, 29-31).

In addition to particular findings arising from each of these theoretical starting-points, all three scholars likewise arrive at one shared conclusion: Darwin's scientific innovation, his rhetorical invention, and even the particular language by which he presents theory and argument all arise together from a single inventional process. Campbell (1990a) is perhaps most explicit on this point. Referring to the various drafts which Darwin developed of his evolution theory, Campbell argues that theoretical innovation and rhetorical presentation inform and constrain one another in Darwin's rhetorical practice: "Each successive theory gave Darwin a temporary base from which to generate additional lines of defense or rebuttal. As Darwin developed the themes of his argument, the terrain which he encompassed came more sharply into focus, which in turn suggested to him further modifications in the form and substance of his ideas" (59). Similarly, Crick argues that the various perspective-taking dialogues which Darwin develops throughout the notebooks "are not simply attempts to dress up an already developed theory, but are actually *constitutive* of his theory development itself. In fact, one would be hard-pressed to find a cohesive theory within the pages of his notebooks" (356). Process approaches to scientific invention, then, attempt to trace the development of theory, argumentation, and even style through time, with all three presented as arising from a single inventional dynamic.

The theoretical tools used in the process approach are suggested by the analyzed texts themselves, and these texts (Darwin's notebooks) are meticulously examined over a span of time. Because of these two aspects, process approaches can provide an impressive level of complexity and sophistication. Campbell (1990a and 1990b), for example, provides a detailed analysis of ways in which Darwin balanced the competing demands of empirical, theological, social, and aesthetic factors in his theory construction: while these elements could be analyzed in isolation, Campbell writes, "we distort Darwin's thinking if we treat them as separate, for they were equal and simultaneous parts of a unified evolutionary vision of God, natural law, man, and the world" (1990b, 76). Insofar as the process approach can deal complexly with such extra-textual factors in the analysis of Darwin's theoretical, argumentational, and stylistic invention, the findings of this approach can be more holistic and varied than the findings of the other two approaches. As useful as topical and analogical approaches may be, they typically deal neither with sociohistorical and cultural context nor with stylistic and presentational aspects of theory or argument.

The process approach allows for detailed and fruitful investigations of complex episodes of theoretical invention. The limitations of this approach, however, arise from the same tight focus and specificity as its strengths. Unlike topical and analogical approaches, the process approach is not readily adapted from one analysis of scientific invention to another. A person wanting to follow Gross, for example, in treating scientific invention as a move from self-persuasion to the persuasion of others could derive many valuable clues and ideas from Gross's own analysis. Such a Grossian analysis could, for example, be carried out when examining, the lab notebooks of a mid-twentieth-century astrophysicist. But such an analysis would have to proceed afresh, since Gross's analysis of Darwin's notebooks does not provide discrete logical, argumentative, or textual structures which could simplify another such analysis. In short, Gross does not provide a generic, portable methodological framework for the analysis of scientific invention. This lack of portability, though in no way lessening the value and interest of analyses made from the process approach, limits their applicability to other inventional episodes, other scientific rhetors, and other time periods.

Examining scientific invention from topical, analogical, or process standpoints thus provides valuable insight into how scientists construct novel argumentation. Analogical and process analyses, moreover, expand our understanding of theoretical innovation, and allow us to describe how theoretical and rhetorical invention relate to one another. But in addition to their individual strengths and weaknesses, all three types of investigation share a limitation: a lack of focus on multimodality. Although scientific communicators routinely employ thought experiments, tables, diagrams, lists, numerical data, and other modalities in developing their texts, all the approaches so far considered remain tightly focused on written language and its use in invention. Though attempts have been made to apply topoi and analogy to visual elements of scientific argumentation—attempts which will be described in more detail in chapter three—nearly all of the scholarly work on scientific invention omits treatment of modalities other than sentences of expository prose. Even those approaches to invention which bring in visual aspects of scientific argument do not also deal with other modalities, such as freestanding lists of items, diagrams, or numerical expressions. Given that scientific invention frequently involves a variety of modalities, then, it would be desirable for scholars to be able to trace episodes of scientific invention multimodally, taking account of how various verbal and non-verbal modalities interact in the generation of scientific explanation, argumentation, and prose. Moreover, it would be preferable if such a multimodal approach to scientific invention could be carried out without first having to set up an exhaustive inventory of inventional moves. Finally, it would be desirable for such an analysis to be applicable, not just to one particular episode of scientific invention, or just one scientist-rhetor or time period, but instead had a broader applicability allowing it to be applied to a variety of different modalities, time-periods, discplines, etc. In the remainder of this chapter, I outline an approach which I believe possesses these attributes.

Invention as Multimodal Re-Representation

My approach to analyzing multimodal invention involves three aspects. In the coming chapters I hope to show how these aspects work together to help Darwin generate both theoretical innovation and the rhetoric necessary to make this innovation persuasive to an audience. First is multimodality. Second is the iterative representation and re-representation of knowledge over time. Third, there are particular knowledge representations which gather previously scattered knowledge together in one place, and in a new modality; I will be calling these *cross-modal perspectivizations*. In the analyses carried out in subsequent chapters, I will show how these three aspects of Darwin's inventional practice work together in the creation of theoretical innovation and rhetorical presentation.

Terms like "modality" and "multimodality" seem unproblematic when we deal with such obviously distinct ways of presenting meaning as written and spoken language, or written language and written diagrams. In other cases, however, it is less obvious what should or should not count as a modality. In my second chapter, for example, I will argue that Darwin sometimes wrote freestanding lists of items, with these lists serving as a modality distinct from sentences of written prose. It is thus important to have a workable definition of modality.

I will adapt my own definition from John A. Bateman's definition (2011), which is derived from the social semiotic tradition. According to Bateman, a modality is 1) a way of presenting meaning to others 2) by purposefully manipulating a material substrate 3) according to a semiotic code. For a rhetorician, the presentation of meaning to others involves a rhetor, a message, and an audience. The material substrate and its manipulations may be quite varied: the vibration of air molecules by the rhetor's voice, meaningful marks which the rhetor makes on a page, or the changing positions of a dancer's body over time. All that is necessary is that this material substrate may be manipulated purposefully by the rhetor, and that it is available for perception by the audience. The "semiotic code" to which Bateman refers may be more or less extensive, more or less complex, and more or less explicitly codified: spoken language, norms for the creation of maps, or conventions governing a particular form of dance could all constitute semiotic codes. The essential point is that there must be a stock of semiotic resources provided by this code from which the rhetor may select—that is, there must be something like a lexicon—and that there must be rules by which these elements may combine into larger units of meaning—that is, something like a syntax or a grammar. Thus, words may be selected, then combined into phrases, clauses, sentences, and paragraphs; the different symbols available for constructing a circuit diagram may be put together into a two-dimensional representation of a real circuit; the different motions available for a certain sort of traditional dance may be combined, simultaneously or over the course of time, by the performer, and so on. In shifting from one modality to another, then, there is a shift in either 1) the material substrate and its manipulations (e.g., from vibrating air molecules to marks on a page) and/or 2) the semiotic code being employed (e.g., from the visual conventions of a map to written English).

The second aspect of my approach involves approaching invention in terms of the iterative representation and re-representation of knowledge over time. This approach derives from research by Linda Flower and John Hayes on the writing process of college students. This research shows that planning a written text involves the iterative re-representation of knowledge over time in a variety of different representational modes (1980, 1981, and 1984): "As writers compose they create multiple internal and external representations of meaning. Some of these representations, such as an imagistic one, will be better at expressing certain kinds of meaning than prose would be, and some will be more difficult to translate into prose than others" (1984, 122). These different representations of meaning are enormously varied, and may include "nonverbal or imagistic representations, abstract knowledge networks, text-based representations, and, finally, formal text representations" (1984, 130). As writers write, then, they take knowledge which already exists in some form or other—an abstract schema in long-term memory, a mental image, an item on a written outline—and re-represent that knowledge in some new representational mode.[7]

Because writers are continually re-representing their knowledge in a variety of modalities, expert writers develop over time "a pool of multimodal representation: notes, drafts, plans, goals, tests, criteria, and imagined reader responses" (1984, 151). This ever-expanding pool of representations eventually moves away from purely cognitive or imagistic representations to the verbal representations which are ultimately revised into finished prose. As writers write, then, the knowledge representations which they produce come to increase in "the number of prose constraints they choose to entertain" (1984, 150). By the end of this process, the knowledge representations entertain all of the constraints of finished prose, and the result is a text which is ready for an audience.

Flower and Hayes's approach provides a useful starting-point for the analysis of multimodal invention. Though we do not have access to cognitive schemas and mental imagery in Darwin's mind, we do have access to at least much of the ecumenical pool of representations which he produced while developing theoretical innovations and the texts by which he would

[7] In addition to knowledge representations which can at least in principle be made public—sketches, tables, thought experiments, sentences of discursive prose, and so on—Flower and Hayes speak about internal and cognitive knowledge representations which can only be made public by re-representing or translating them in some way: mental images, bits of procedural knowledge, schemas in long-term memory, and the like. They thus typically use terms like "representational mode" or "modality" more broadly than I use the term "modality."

eventually transmit those innovations. By selecting a particular series of representations relating to a particular inventional process, we can investigate what led Darwin to shift, for example, from sentences of written prose to a diagram, or from a series of numerical measurements to a paragraph. Because each such modality has different limitations and affordances, we can look at what Darwin was able to gain from each such representational shift and use this knowledge to see what role multimodality plays in his inventional practice.

The study of Darwin's notebooks lacks something which Flower and Hayes had access to in their research on the writing process: purely cognitive or "internal" knowledge representations. However, studying Darwin's notebooks also involves a complication not present in their research. In addition to developing argumentation and discursive prose, Darwin is also developing theoretical innovation. To some extent, of course, the writing process always involves determining, in tandem, both what one is going to write and how one is going to write it. Particular lines of argument or examples arise or fall away, the scope of the argument broadens or narrows, and so on. But in his notebooks, Darwin is not merely determining the scope or particulars of an argument; he is developing scientific explanations which fit his existing data and observations. Though political orators may find new examples or turns of phrase in the process of invention, they are not likely to have to produce a wholesale picture of what their nation is, what their candidacy does, or the complete history of a particular issue in the process of constructing a particular speech.[8] For Darwin, however, the development of theoretical innovation to be transmitted to a scientific audience takes up the bulk of what is

[8] Naturally, it is possible that political candidate and his or her advisers may have to develop at the beginning of a campaign a comprehensive picture of the campaign and a comprehensive rhetorical strategy. Examining this sort of inventional situation, prior to the drafting of any particular speech, might thus have more in common with my examination of Darwin. The point remains, however, that the development of such a comprehensive campaign rhetoric is not the same as the development of particular speeches or texts instantiating that rhetoric, and that Flower and Hayes's research on the writing process alone would probably not be adequate for its analysis.

happening in his notebooks, particularly between the years 1837-1839. Only once this theoretical invention begins to take shape do we Darwin deal in more depth with particulars of arrangement, style, and presentation.

In order to deal with this epistemic aspect of Darwin's invention, Flower and Hayes's picture of iterative re-representation must be expanded to deal in more detail with the ways in which a change in knowledge representation can yield novel inferences and insights. As we will see in the coming chapters, a particular kind of knowledge representation is central to Darwin's inventional practice. This is a knowledge representation which 1) *gathers together previously scattered knowledge* into a single representation; and 2) represents that knowledge *in a different modality* than it was presented in before. For example, when Darwin is developing his evolution theory in 1837, he has a variety of scattered facts about the taxonomic relationships among various organisms, both living and extinct, which he has seen in various locations all over the world. This knowledge exists in a variety of forms: schemas in long-term memory, presumably; visual recollections of fossils and living animals he has seen; sentences of prose in various notebooks written during and immediately after his voyage on the *Beagle*, and so on. But in order to better understand how all these different organisms and their relationships work, Darwin takes this previously scattered knowledge and puts it together into a single, highly abstract diagram which is formally similar to a family tree. This diagram encodes various relationships which Darwin has seen or hypothesized throughout his voyage, putting them together in a novel modality which allows him to produce novel inferences about how evolutionary history gave rise to those relationships.

Such knowledge-gathering representations in a new modality I will be calling *cross-modal perspectivizations*. Because they shift existing knowledge to a new modality, such representations allow different cognitive processes to be brought to bear on that knowledge. For example, as we will see in the next chapter, when trying to understand how asexual reproduction in plants works, Darwin generates a freestanding list of natural phenomena which are similar to budding in plants. Having created this list, Darwin does not need to read it according to the typical syntactical patterns of English prose, such as topic, predicate, modifier, complement, and so on; rather, he has only to find some similarity among these list items other than their kinship to budding. Only the semantic aspects that all list items share matter to Darwin, so instead of reading and writing sentences of prose, Darwin has only to find an underlying similarity. The modal shift thus allows a shift in how new inferences can be generated from existing knowledge.

Also, because cross-modal perspectivizations gather together previously scattered knowledge, concepts, attributes, and relationships which were not previously conceived together can be conceptually related from a single cognitive perspective. In the case of Darwin's tree diagrams, all the various genealogical and taxonomic relationships cluttering Darwin's brain and notebook pages are perspectivized together as branching lines of varying lengths organized in a tree. Rather than having to shift from knowledge of one relationship among animals to another, Darwin can schematically present all of them to himself in a single way, allowing for various pieces of knowledge to be related straightforwardly with one another. Thus, though Darwin's inventional practice involves the same sorts of dynamics that Flower and Hayes describe in their research on the writing process, this gathering of scattered knowledge in a new modality is an essential aspect not addressed in their model.

Method

In each of the three subsequent chapters of this project, I will limit myself to one particular non-discursive modality, investigating how that modality yields theoretical and rhetorical innovation in one particular process of Darwin's scientific invention. My method will involve moving through Darwin's notebooks, unpublished drafts, and published writings chronologically, tracing moments when Darwin shifts from sentences of discursive prose to that modality and back again—that is, I will examine Darwin's iterative re-representation of knowledge between these two modalities. I will also be paying special attention to the cross-modal perspectivizations by means of which Darwin gathers previously scattered knowledge together in a different modality than it was previously represented in. My purpose will be to determine how Darwin developed both theoretical innovation and the plausible presentation of that innovation to audiences by way of this multimodal invention. Research questions include:

- Is the development of theoretical innovation the same process as rhetorical invention, or are the two distinct?
- What role does multimodality play in the development of theoretical insight? In the development of argumentation?
- How is multimodal scientific argumentation produced over time?

As I will show in the coming chapters, the insights produced with this method of analysis are unique and instructive. For example, I am able to show that theoretical innovation and rhetorical presentation are developed by means of a single inventional process. In the beginning, this process deals very little with specifics of rhetorical strategy, style, or presentation to an audience; at the end, such concerns dominate the process. Throughout, however, the same elements and the same processes govern the inventional process. This is, in part, because of how cross-modal perspectivizations work in Darwin's inventional process (and, presumably, in the inventional processes of other scientists). When Darwin, for example, tries to come to grips with the various taxonomic and genealogical relationships among living and fossil organisms that he is considering in 1837, he generates a series of crudely sketched family tree diagrams. As we will see in chapter three, these diagrams provide Darwin with novel insights about evolution and its effect and lineages and taxa of organisms—indeed, this is why Darwin produces these diagrams in the first place. In addition, however, Darwin gains something else: the cross-modal perspectivizations themselves. As he prepares his theory for publication, Darwin experiments with new ways of drawing such tree diagrams, adds more regimentation of the time dimension, tries to map existing taxa of organisms with such trees to better understand their evolutionary history, and so on. Ultimately, a still later revision of this tree diagram, boasting visual conventions imported from plane geometry, becomes the sole illustration of *On the Origin of Species* (1859). Darwin's published diagram is thus a revised version of hastily sketched perspectivizations scribbled in a notebook to understand something puzzling. The revisions which Darwin's tree diagram undergoes between 1837 and 1859 ultimately affect even the tiniest aspects of the diagram, gradually shaping it into the anchor of a number of visual-verbal arguments in that text. From the first rough attempts to understand a natural phenomenon to seemingly trivial details of visual convention in the finished diagram, then, Darwin's invention is one single, iterative, multimodal, rhetorical process.

Analyzing scientific invention in terms of iterative re-representation of knowledge and cross-modal perspectivizations is thus able to deal with inventional processes from the earliest, clumsy attempts to generate insight about nature to the final revisions of a multimodal argument.

There are, however, limitations to this approach; it can never replace existing approaches to the study of scientific invention. Unlike existing topical approaches, for example, my approach does little to examine a scientist's inventional choices in terms of the wide array of available inventional choices. Instead, it can only examine the diachronic inventional process as it in fact happened. Likewise, it cannot deal with analogical invention nearly as well as existing analogical approaches, since analogies are typically presented in sentences of discursive prose, and thus do not mark the sort of modal shift which my own approach concentrates on. Finally, though it shares with process approaches a concern with tracing one particular historical episode in detail, and though it has readier applicability to the analysis of a variety of inventional episodes, it lacks one important strength of process approaches: it does not examine theological, philosophical, or sociohistorical contexts of scientific invention. Thus, though my approach is promising in the detailed investigation of multimodal scientific invention, it cannot replace or obviate existing approaches.

In comparison with other ways of investigating scientific invention, however, this approach does have two unique virtues. First, unlike these other approaches, it is specifically designed to handle multimodal invention, and indeed focuses upon the role which multimodality plays in scientific invention. Second, this approach, unlike process approaches, is applicable to other scientific contexts, rhetors, and time periods than those specifically analyzed here. This is because in order to examine *any* episode of scientific invention, it is necessary to have access to materials which a scientist produced during that episode. It is also necessary to understand the concepts, observations, and data with which that scientist is working. The application of this method of analysis to a particular episode of scientific invention requires little additional preparation. The analyst must simply 1) find cases where the scientist shifts from one modality to another—diagram to body of numerical data, freestanding list to paragraph of prose, digital photograph to verbal description, and so on—and determine what new insights the scientist gains from this modal shift; and 2) be particularly attentive to representations which gather knowledge which was previously scattered among a variety of different knowledge-representations into a single paragraph, table, diagram, computer model, etc. This method is by no means algorithmic, but since it only involves relatively clear-cut concepts like "modality" and "re-representation," it is adaptable to the study of scientific invention outside of the examples of Darwin's practice investigated here. For this reason, other researchers should be able to use it in other studies of multimodal scientific invention in ways which augment, elaborate upon, complicate, or problematize the results at which I arrive in the chapters which follow.

The Chapters

In chapter two, I will examine Darwin's use of list-making as an inventional strategy employed in his generation of the *gemmule* concept. This concept was central to Darwin's theory of the inheritance of traits (his so called *pangenesis* theory) published in the second volume of *The Variation of Animals and Plants under Domestication* (1868). I show that Darwin borrowed list-making as an inventional strategy from John Herschel (1831), who in turn borrowed it from Francis Bacon (1960). This inventional list-making was a strategy in which a puzzling natural phenomenon was investigated by massing as many instances as possible of that phenomenon. Once these heterogeneous phenomena have been listed, the scientist can then read off these listed phenomena their underlying similarity, subsequently using this similarity to generate theoretical innovation. Since the knowledge of natural phenomena in this list are scattered across many different knowledge representations, the list is a cross-modal perspectivization. Having used this perspectivization to gain novel insight into the inheritance of traits, Darwin subsequently revises the list, adding and reordering items until he has produced a piece of finished prose—no longer a freestanding list, but instead a rhetorical figure known as *congeries*—which does rhetorical tasks not carried out by the original cross-modal perspectivization. From the development of theoretical innovation to fine-scale decisions about the ordering and wording of individual list items in his finished text, then, Darwin's list-based invention constitutes a single, iterative process governed by (among other things) the construction and revision of lists.

In chapter three, I analyze Darwin's use of family tree diagrams in his transmutation notebooks to clarify evolutionary mechanisms for himself, and I examine how later versions of these diagrams were employed in the 1859 presentation of his evolution theory in *On the Origin of Species*. In the notebooks, Darwin's diagrams suggested novel reasoning strategies to him which might prove useful in solving scientific problems. For example, the visual similarity of branchings at different taxonomic levels in his sketched diagrams suggested to Darwin that an inference applicable at, say, the species level might also be effective at higher taxonomic levels as well. Having found this shifting of levels useful at generating plausible new inferences, Darwin comes to employ it repeatedly in future inventional work. In addition, Darwin experiments with his incipient genre of the evolutionary tree diagram over the next two decades, trying out various representational practices which come to constitute stable visual conventions—for example, adding more regimentation to the time dimension of the diagram. In his multimodal invention between 1837 and 1859, then, Darwin develops not just inferences about evolutionary history but also reasoning strategies and representational practices, as well. Moreover, as time goes on, Darwin's revisions to his tree diagram involve more and more the possibility of a coherent rhetorical strategy centered around the diagram. Decisions which Darwin makes about how specifically to regiment the time dimension, label taxa, and so on come to be informed by a comprehensive, multimodal rhetorical strategy grounded in the diagram. Darwin's visual-verbal inventional process, then, starts with hastily sketched diagrams intended to generate novel inferences about nature, continues through rounds of multimodal revision, and concludes as decisions about theory, argumentation, and overarching rhetorical strategy begin to inform and constrain one another.

In chapter four, I examine Darwin's process of manipulating numerical data while investigating a series of stepped cliffs on the Argentinian coast during the *Beagle* voyage. I show how Darwin employed an existing special topos used by the geologist Charles Lyell, adapting and expanding it to explain the Argentinian cliffs. Having developed a provisional explanation for the Argentinian cliffs, Darwin then took the chaotic masses of cliff-elevation data from his measurements along the coast, gradually simplifying and manipulating them in an attempt to square them with the Lyellian explanation he had developed. The cross-modal perspectivizations which Darwin produced in his analysis of this data were subsequently revised as parts of the multimodal argument by which he presented his Lyellian explanation to a scientific audience—the first chapter of his 1846 book *Geological Observations on South America*. As Darwin revised these cross-modal perspectivizations, he was also developing the overarching rhetorical strategy of the chapter as a whole. These two processes—revising perspectivizations and developing rhetorical strategy—constrained and informed one another by the end of his inventional process.

My analyses, then, will demonstrate that Darwin's inventional logic involved the iterative re-representation of knowledge over time and cross-modal perspectivizations, and that these two aspects worked together to generate both theoretical and rhetorical innovation. Darwin's inventional process begins with the development of novel inferences about nature, and the development of cross-modal perspectivizations useful in this inference-development. With revision, these inferences and perspectivizations are developed into multimodal argumentation useful in presenting theoretical innovation to a scientific audience. But by the end of the inventional process, Darwin has developed, not just particular elements of a multimodal argument, but overarching rhetorical strategies which govern large stretches of text. The analysis of multimodal scientific invention in this dissertation, then, provides an account which unites knowledge construction, knowledge presentation, and rhetorical strategy into a single process. Moreover, the analysis used to investigate this process can be adapted as needed to future analyses of other episodes of multimodal scientific invention.

Chapter Two: Lists as Inventional Resources

> I am not at all surprised that you cannot digest Pangenesis; it is enough to give any one an indigestion; but to my mind the idea has been an *immense* relief, as I could not endure to keep so many large classes of facts all floating loose in my mind without some thread of connection to tie them together in a tangible method.
>
> Darwin's 22 April 1868 letter to botanist George Bentham[9]

> It is characteristic of a well-directed mind to observe the likeness even in things very different.
>
> Aristotle, *Rhetoric* 3.11.5.

Charles Darwin had a peculiar habit. In the so-called "transmutation notebooks" which he filled with theoretical speculations between 1837 and 1839, he had a tendency to make lists. This habit appears throughout the notebooks, and was central to Darwin's methodology. Moreover, some of these lists also appear, in revised form, in Darwin's unpublished manuscripts and even his published writings. This frequent list-making is all the more interesting because it has been investigated by none of the historians of science who have studied Darwin. There is no mention of Darwin's list-making at all in the seminal works of Browne, Herbert, Hodge, Kohn, Ospovat,

[9] All references to Darwin's letters are from Burkhardt and Smith's 20-volume compilation of Darwin's correspondence (1985-2013).

Sloan, or Sulloway.[10] Neither have rhetoricians of science who have examined Darwin's process of theoretical invention in the notebooks addressed this list-making (e.g. Campbell 1990a and 1990b, Crick 2005, Gross 2006). In this chapter, I investigate this neglected aspect of Darwinian inventional practice.

I will examine Darwin's use of list-making in the generation of both theoretical and rhetorical innovation, following two particular lists from his transmutation notebooks of 1837-39 to published presentations of theory in 1859 and 1868. Recent scholarship in the history and rhetoric of science has begun to attend to the inventional possibilities of lists in science, both in the generation of theory and in rhetorical invention. Unfortunately, this scholarship tends to concentrate either on the use of lists in developing theory or the use of lists in developing argumentation. Because of this concentration on either theoretical or rhetorical innovation, significant connections between the generation of insight and the generation of publishable argument are rendered invisible.

In this chapter, I begin by examining Darwin's list-making as a tool which he used to develop novel theoretical insights about nature. I show that Darwin derived this list-making technique from John Herschel (1831), who in turn derived it ultimately from Francis Bacon (1960). When faced with a theoretical or explanatory difficulty, Darwin lists natural phenomena which seem intuitively to share some similarity. Having produced this list, Darwin then examines the items on it in order to find another similarity besides the one used to make the list

[10] In addition to the essays in Kohn 1985, see Browne 1996 and 2003, Herbert 1995 and 2005, Kohn 1980, Ospovat 1995, Hodge and Radick 2003, Sloan 2003, and Sulloway 1982. I have also searched scholarly databases like JSTOR for terms like "Darwin and lists," "Darwin and series," "Darwin and seriality," "Darwin and congeries," and so on without finding any treatments of this subject. Needless to say, the secondary scholarship on Darwin is voluminous, so it is always possible that some mention has been made of Darwin's list-making that I have simply not been able to find. Given the omnipresence of lists in Darwin's notebooks, unpublished manuscripts, and published writings, however, the difficulty in finding such possible scholarship is striking.

in the first place. Insofar as this additional similarity among list elements may be found, it allows Darwin to reconceptualize these items as examples of a larger category of natural phenomena. For example, as we will see, Darwin attempts to better understand the nature of asexual reproduction in plants by listing natural phenomena which seem similar to budding—the regeneration of limbs in lizards, the creation of two planarian worms when a single such worm is cut in half, and so on. Darwin then uses this list to develop his gemmule concept.

Insofar as the different list items arise from knowledge representations in a variety of modalities—schemas in long-term memory, mental images, texts which Darwin has recently read, etc.—Darwin's lists gather previously scattered knowledge together into a single representation so that this knowledge can all be examined at one time. Moreover, as I will argue in the next section, Darwin's lists constitute a modality distinct from sentences of discursive prose. Darwin's inventional lists are therefore cross-modal perspectivizations. The list-making technique which Darwin has borrowed from Bacon and Herschel, then, is a repeatable means for generating a particular form of cross-modal perspectivization, and thus of gaining theoretical insight and, with further revision, rhetorical innovation.

But having used a list investigatively, Darwin has not only developed novel theoretical insight: he has also created the list itself. Having this investigative list at his disposal, he can elaborate upon its elements, add or subtract elements, and so on in further rounds of inventional work. Moreover, this revision allows Darwin's list to take on rhetorical powers which the original, investigative list did not have. For example, Darwin's revised lists can may demonstrate the impressive explanatory power of a theoretical concept or show the actual relatedness of natural phenomena which at first sight seem distinct and heterogeneous. The rhetorical powers gained as Darwin revises his lists are nothing new to the rhetorical tradition. Indeed, rhetoricians have long studied rhetorical figures that involve list-making. In showing how Darwin's lists gain new rhetorical features, then, I will use the rhetorical figure of *congeries*. Thus, a cross-modal perspectivization is revised by Darwin to produce a rhetorical figure in the presentation of his finished text.

Darwin's investigative lists thus simultaneously give him new knowledge and new knowledge-representations. By revising and recombining these elements in published work, Darwin is able to take revised forms of his investigative lists and redeploy them as available means of persuasion. Thus, Darwin's inventional list-making involves 1) an inventional technique that directs him in the construction of a particular kind of cross-modal perspectivization; 2) the cross-modal perspectivization itself, which can be developed in further revision to possess new rhetorical features; and 3) a finished congeries in the published presentation of theory. Darwin's list-making thus takes him from attempts at better understanding nature to fine-scale decisions about how to order and phrase list-items in his finished prose. His theoretical and rhetorical innovation, then, owe their development to a single inventional process which changes gradually in its character over time.

Lists as Inventional Tools

The scientific use of lists is only beginning to receive sustained scholarly attention.[11] Historians of science have begun to examine how list-making practices, sometimes borrowed from commercial and bureaucratic spheres, serve in the presentation of scientific results, the development of museum exhibitions, and the connection of scientific endeavors to

[11] Aside from Hopwood, Schaffer, and Secord's (2010) survey of the uses of scientific lists, the earliest major development in this scholarship was a 2012 special issue of *Isis*.

administrative, institutional, and domestic ones (Hopwood, Schaffer, and Secord 2010; Delbourgo and Müller-Wille 2012). Some of this investigation has revolved around the inventional uses to which lists can be put, both theoretical and rhetorical. These scholars have shown that lists can serve a variety of inventional purposes, both in the generation of scientific explanations and in the generation of persuasive discourse. By allowing scientists to externalize transient and temporally scattered thoughts and ideas in a durable and coherent form, lists give scientists the ability to generate new groupings of concepts, and to alter the shape of existing concepts. Moreover, since a list can always be added to, subtracted from, or used in the creation of other knowledge-representations, lists also give scientists new inventional options that were not available before list creation. Finally, lists provide argumentative structures which can perform a variety of functions in published argumentation.

Historians of science have investigated the inventional uses of lists in scientific notebooks. Müller-Wise and Charmantier (2012), for example, examine how the eighteenth century systematist Linnaeus used lists to generate insight about how best to categorize plants. On Müller-Wise and Charmantier's account, Linnaeus's lists served as "research-enabling technologies," that is, as "material tools for organizing the acquisition and accumulation of knowledge" (744, 752). By listing the types of plants which he'd observed in three different Swedish provinces, Linnaeus could turn from scattered memories of an enormous variety of plant species to a coherent written inventory, using this inventory to carry out further inventional steps. This list of plants, probably composed in 1728, was then employed as a resource for three additional lists, all apparently produced the following year (746). Each of these three lists took items from the first list, but was limited to only one of the three Swedish provinces previously examined by Linnaeus. More importantly, Linnaeus used a different taxonomic system for each of these three new lists: “Whereas the plants from Scania were arranged according to Rivinus’s system, Linnaeus followed the system of Joseph Pitton de Tournefort (1656-1708) for the plants of Smolandia and the system of John Ray (1627-1705) for those of Roslagen” (748). By changing his 1728 list of plants in these three provinces to three distinct lists, each employing a different system of botanical taxonomy, Linnaeus could experiment with these competing taxonomic systems, “getting to know their respective advantages and disadvantages in the process (Müller-Wise and Charmantier 2012, 748). Lists thus allowed Linnaeus to move from inventory to experimentation with taxonomic systems to judgments about the problems and benefits of these taxonomic systems.

Likewise, Hoffman (2013) examines the inventional value of lists in scientific notebooks, concentrating on the physicist Ernst Mach. Hoffman describes lists as a sort of “writing procedure,” that is, as “a sequence of actions, flexible within certain tolerances, that results in a graphical arrangement of written traces” (285). Other writing procedures commonly used in science include the recording of experimental results and the production of tables (284). Such writing procedures, because they are relatively flexible sequences of simple actions, are easy to apply to a variety of purposes. Lists in particular are valuable to the scientist because they exteriorize what a scientist is thinking about in such a way that thoughts which occur to the scientist one-by-one can all be examined simultaneously on paper. In lists, Hoffman suggests, “The temporality of mental activities (one idea after another) is replaced by the spatial simultaneity of written items that may now be *related* to each other in multifarious ways without being limited by the ongoing stream of thought and the capacity of the human memory” (292). Further, this exteriorization of the mind’s contents allows for further operations, such as the addition or elimination of list items, or the use of brackets and other notations to regroup items into sub-lists, emphasize or de-emphasize particular items, and so on (292-94). The list, then, is a durable exteriorization of the mind's contents which may then serve as the basis for further iterations of inventional activity.

Though he is a historian and not a rhetorician of science, Hoffman uses this idea of the list as a writing procedure to examine an episode of rhetorical invention: how Ernst Mach used lists to develop topics for an 1895 speech on the role of accident in scientific discovery which he was to give at the University of Vienna (290). Mach's rhetorical invention involved writing ten pages of lists. He began by producing several underlined headings (*Zufall*, *Psychologie*, and so on), listing words or short phrases below each heading. The headings appear to have been major topics, with the words and short phrases being particular elements, examples, or arguments (292-93). As these lists became more complete, Mach began crossing out some items, underlining others, and using various notations to develop connections among items: "Some [list items] are more closely linked with each other (brackets), which 'distances' those items nearby that were not included. Some items may prove central (underlines) while 'debasing' those that are not highlighted. And other items inspired new elements (additions), testifying to the 'incompleteness' of the original list" (293). Having reworked his multi-page list of topics and sub-topics over time, Mach finally produces a new list of "themes," one which is very similar to the themes actually spoken about in his eventual 1895 address. However, "none of these 'themes' coincides directly with any of the headings of the lists that Mach had noted on the previous pages. Obviously, the procedure of listing and marking led Mach to an organization of his ideas that he had not envisioned when he began the process" (294). On Hoffman's account, then, the process of making and revising lists allowed Mach to progressively revise his understanding of the topics of his speech and their interrelationships, generating new insights about how to structure his speech and what examples and arguments to employ.

The inventional value of lists has also been investigated by Jeanne Fahnestock. Fahnestock (2002) examines lists, not as freestanding inventional resources of the sort we find in the notebooks of Linnaeus and Mach, but rather in terms of rhetorical figures which construct series of items. She argues that such figures are not just stylistic ornaments, but inventional tools able to provide both theoretical insight and novel argumentation. On Fahnestock's account, some figures of speech are "epitomes of certain durable lines of argument," expressing a particular bit of topical logic so succinctly that "the argument can be created almost automatically by creating the figure" (40). An incrementum, for example, is a rhetorical figure in which a series of items is listed in ascending or descending order. The canonical example provided by Quintilian is typical: "It is a sin to bind a Roman citizen, a crime to scourge him, little short of the most unnatural murder to put him to death; what then shall I call his crucifixion?" (qtd. in Fahnestock (2002), 92). In this example, the act of crucifying a Roman is attacked as unacceptable by placing it at the end of a series of condemnable acts. Naturally, it is also possible to construct an argument praising something by associating it with the end of a series of laudable things: "Neither silver, nor gold, nor precious stones might be compared to here vertues" (Peacham, qtd. in Fahnestock 2002, 91-92). Merely by constructing a series of laudable or damnable objects, then, an epideictic argument is almost automatically constructed by the syntactical logic of the incrementum.

But Fahnestock notes that series-constructing figures are useful for more than just epideictic oratory. Because of its directionality, and because of the small difference between adjacent steps in the series, series figures like incrementum can be used to turn a difference in kind between two concepts into a difference in degree. Reviewing Darwin's use of series figures in the *Origin*, Fahnestock (1996) notes his frequent use of *gradatio,* a figure which has the same directionality as incrementum but which emphasizes this directionality by having elements at the end of one list element repeated at the start of the next list element: "We glory in tribulations also: knowing that tribulations worketh patience; And patience, experience; and experience, hope: and hope maketh not ashamed" (Romans 4:3-5, King James Version; qtd. Fahenstock (2002), 93). Throughout the *Origin*, Darwin is faced with a problem: in his readers' experience, species do not change, and there seem to be clear demarcations between different species. One way Darwin deals with this problem is by trying to connect, on one hand, the seeming stability and separateness of species with, on the other, the enormous variability in the traits of individual organisms. He does this by way of a gradatio: "Certainly no clear line of demarcation has as yet been drawn between species and sub-species. . . : or, again, between sub-species and well-marked varieties, or between lesser varieties and individual differences. These differences blend into each other by an insensible series" (Darwin 1859, 51; qtd. in Fahnestock (1996), 28). On Fahnestock's account, then, the directionality of series-producing figures like incrementum and gradatio allows for a list of items to serve a variety of argumentative functions, such as praise, condemnation, or the dissolution of a sharp boundary between two seemingly distinct concepts.

But Fahnestock also sees this inventional value of series-constructing figures as extending even to the generation of theoretical innovation. For example, Fahnstock argues that the astronomer William Herschel employed incrementum to understand the life cycles of stars (2002, 105-08). Herschel was puzzled at the variety of stellar phenomena in the night sky. He was able to make sense of these phenomena by means of an analogy with the world of plants: just as the different stages in the life of a plant might all be simultaneously visible in a garden, so might the different sorts of stellar objects visible in the night sky be stages in the life cycle of stars. Fahnestock does not examine any of Herschel's notebooks and planning documents, but shows that in an early publication from 1789, this series reasoning is already in full force:

> For, to continue the simile I have borrowed from the vegetable kingdom, is it not almost the same thing, whether we live successively to witness the germination, blooming, foliage, fecundity, fading, withering and corruption of a plant, or whether a vast number of specimens, selected from every stage through which the plant passes in the course of its existence, be brought at once to our view. (qtd. in Fahnestock (2002), 106)

Taking the series of stages in the life cycle of plants as something already clear, Herschel attempted to produce a second series—the series of stages in the life cycle of stars—and to overlay it onto the first series. Fahnestock shows how, in future rounds of invention between 1789 and 1811, Herschel takes the various nebulae and other stellar phenomena which he sees through his telescopes and attempts to arrange them in a plausible series which explains the great diversity of stellar phenomena in terms of a simple schema of star development (106-08). Thus, the topical logic of series-making figures like incrementum is useful, not just in the creation of argument, but also in the generation of novel scientific explanations. [12]

Scholarly work in the history and rhetoric of science, then, shows that the construction of series of items—whether as freestanding sets of inscriptions or as rhetorical figures in a finished text—can serve in the construction of both theoretical and rhetorical innovation. Lists allow

[12] As Fahnestock notes, Herschel also relied upon a form of analogical reasoning to generate this conclusion, which she treats in terms of Perelman and Olbrechts-Tyteca's (1969) concept of double hierarchy arguments (337-345; Fahenstock 2002, 105-08).

scientists to externalize the mind's contents into a durable form which can be examined all at once, and at leisure. Moreover, this externalization can be revised in future rounds of invention: items can be added, subtracted, altered, or regrouped, and a list may be used to generate other lists. These further steps can alter the scientist's understanding of the overarching concept of the original list, and of the relationships among the elements comprising it. Moreover, lists can be presented to readers as ways to praise or condemn something, or to dissolve the differences between two seemingly distinct concepts, or to generate an analogical argument with another, already existing series. In short, the "writing procedure" of listing a series of items can serve a variety of investigative and argumentative purposes in science.

But the existing scholarship on the inventional power of lists takes one of two approaches: either lists are examined as a way of generating theoretical innovation, as in Müller-Wille and Charmantier's examination of Linnaeus, or they are examined as a way of generating rhetorical innovation, as in Hoffman's examination of Mach.[13] Scholars interested in the inventional value of lists have not so far dealt in detail with how a particular process of list-making can be used first to generate theoretical innovation and then to present that innovation to a scientific audience. Even when Fahnestock examines Herschel's use of incrementum to categorize stellar phenomena, or Darwin's use of gradatio to rhetorically dissolve the difference between species difference and individual difference, she limits her analysis to the published

[13] Hoffman also briefly describes a short episode of Mach's theoretical invention, but does not trace it through to the final, published version of Mach's theory.

writings of these scientists. Scholars have not traced lists from the generation of theoretical innovation to the presentation of final argument to a scientific audience.[14]

In the following section, I make the case that lists, at least in some instances, constitute a modality which is distinct from sentences of prose. This will be important in showing how Darwin's movement from prose to lists and back again constitutes a multimodal process of invention, and also shows why this multimodality should matter. Next, I introduce the rhetorical figure of congeries as a way to analyze Darwin's inventional use of lists. I then describe how Darwin, borrowing from the astronomer John Herschel, uses lists in his transmutation notebooks to develop novel insights into nature. Next, I show how the lists which Darwin develops in these notebooks are subsequently revised and repurposed in presentations of theory intended for scientific audiences. I hope to show that the full inventional value of lists can only be understood when we see lists, not just as tools for investigation or as stylistic structures instantiating an argument, but also as revisable knowledge-representations which help the scientist to move, by small steps, from novel insights to presentable, finished prose.

Lists as a Distinctive Modality

In an essay titled "Toward a Concept of Postmodernism," Ihab Hassan (1987) attempts to define postmodernism, and to distinguish it from modernism. After briefly outlining how he understands postmodernism and describing some of the difficulties involved in defining it, Hassan provides a pair of lists, presented as a two-column table. He introduces these lists by

[14] For the most part, this is also true of the other figures which Fahnestock addresses in *Rhetorical Figures in Science*—though her treatment of Faraday's use of anitmetabole constitutes an important and interesting exception (144-150).

asking “Can we distinguish postmodernism further? Perhaps certain schematic differences from modernism will provide a start” (5). He then provides, on the left side of the page, a list of terms under the heading “Modernism,” including “Purpose,” “Hierarchy,” and “Determinacy” (6). On the right side of the page, under the heading “Postmodernism,” he includes terms like “Play,” “Anarchy,” and “Indeterminacy” (6). Hassan then uses these two lists to show what he sees as the fundamental “postmodern tendency, a tendency which he dubs “indeterminance.” Hassan then spends the remainder of the essay describing this tendency.

Hassan’s double list or table, like the paragraphs preceding it, is made up of written words. This suggests that these lists are in the same modality as the rest of the essay. On the other hand, the reader must approach these lists differently than s/he approaches the remainder of the essay, and must interpret it in a different way. Are these lists then in the same modality as the other written language in the piece, or in a different modality? In the previous chapter, I presented a definition of modality derived from Bateman (2011). According to that definition, we can determine whether two knowledge representations belong to different modalities by determining whether they differ in 1) the physical substrates whose manipulation yields the two representations—the vibrated air molecules, inscribed pieces of paper, etc.—and/or 2) the semiotic code in which the meaning representation is presented—the lexical items of the code, their syntactical relations, and so on. In Hassan’s lists, we see a meaning representation which involves the same material substrate and the same purposeful manipulation as the prose comprising the remainder of his essay. In its semiotic code, however, Hassan’s lists are somewhat different. The lexical items—in this case, English words—are the same. However, their syntactical combination into larger units of meaning is not. In the rest of the essay, words are combined into phrases, clauses, and sentences. In the lists, however, each lexical item is only subject to two syntactical connections: first, the connection between any particular list item and the other items in the same column; and second, the connection between any particular list item and the antonym directly across from it in the other column. The typical syntactical relations available in sentences of prose—relations among subjects, predicates, modifiers, and complements, for example—do not apply. Meaning is derived by finding commonalities with other items in the same column, and by semantic contrast with the corresponding member in the other column. While the text before and after Hassan's double list involves the reader in gradually building meaning from phrase to phrase and from sentence to sentence, gradually producing a semantic whole, Hassan's lists do not. Rather, the reader of these lists builds a schematic representation of what modernism is with the aid of the first list, and of what postmodernism is by way of the second—aided, of course, by contrasts between individual list items. To a large extent, then, Hassan's lists constitute a distinct modality from the paragraphs of prose before and after them. In shifting from prose to the double list, then back to expository prose which helps to unpack the lists, Hassan is presenting what could reasonably be called a multimodal argument.

As we will see in the remainder of this chapter, the lists employed by Darwin in his notebooks for inventional purposes are likewise modally distinct from his sentences of prose. There are two important differences, however. First, Darwin's list-making practice is not a strategy that he employs occasionally in finished writing; rather, it is an inventional practice derived from the scientific methodology of John Herschel, who in turn adapted it from Francis Bacon. Second, Darwin's notebook lists have only he himself as their audience; rather than using lists to persuade readers, he instead uses them to develop insight into some natural phenomenon which he uses a list to investigate. Over time, however, Darwin revises these lists—adding, subtracting, and reordering items—until they are ready to include in published writing. These published lists are not just alterations of the notebook lists, however; they also take on rhetorical features which their precursors in the notebooks did not have. In part, this is because in revising them, Darwin turns them from a freestanding inventory of items into sentences of discursive prose; however, the reordering and rewording of list items also allows Darwin's lists to produce epideictic and argumentative effects which were absent in his more modally distinct notebook lists.

Congeries as an Investigative Tool

Darwin's transmutation notebooks are filled with lists. Since Darwin never intended for these notebooks to be published, and never, so far as we know, showed them to anyone, these lists do not seem to have been intended to persuade an audience. Rather, Darwin used them to clarify his own understanding of particular natural phenomena. Like other aspects of his scientific practice, John Herschel's 1831 book *A Preliminary Discourse on the Study of Natural Philosophy* appears to have been the source for Darwin's approach to investigative list-making. Herschel, in turn, derived this approach from Francis Bacon. By examining these origins of Darwin's inventional use of lists, and by understanding this use in terms of the rhetorical figure congeries, I will show that Darwin used lists of natural phenomena and events which seemed intuitively similar to one another as a way to develop theoretical innovation. The list of similar phenomena, once gathered together from previously scattered knowledge representations, could be examined at leisure in order to generate novel inferences about nature.

Like incrementum and gradatio, congeries is a figure which constructs a series.[15] Unlike these other figures, the list has no directionality; it is merely an inventory of related, though distinct, items. Peacham gives an example from the book of Galatians: "The deeds of the flesh are manifest, which are these: Adultery, fornication, uncleanness, wantonness, worshipping of images, witchcraft, hatred, variance, zeal, wrath, strife, seditions, sects, envying, murder, drunkenness, gluttony, and such like" (132).[16] With congeries, rhetors "multiply and heap many words together, *signifying diverse things of like nature*" (Peacham 132; emphasis added).[17] Similarly, Puttenham (1589) calls congeries "the heaping figure," by which "we lay on such load and so go to it by heaps as if we would win the game by multitude of words & speeches, *not all of one but of diverse matter and sense*" (197, emphasis added). In spite of their variety, and though they lack the direction of incrementum or gradatio, the heterogeneous expressions in a congeries all evoke in the minds of message recipients some coherent category or concept. Thus, in Peacham's example from Galatians, the overarching concept of *sin* ("the deeds of the flesh") is abundantly clear.

As Fahnestock (2011) notes, "a series constructs a category" (241).[18] Describing the use of massing figures like congeries in Renaissance poetry, Adamson (1999) similarly notes that such figures call forth a "superordinate term" in the minds of readers which "does not denote a so-called natural class like 'creature' but an artificial class created by a particular world-view or

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[15] Like most rhetorical figures, the figure which I discuss here is known by a variety of Greek and Latin names. Quintilian, for example, refers it as *synathroismus* (8.4.26-27), while Fahnestock (2002), following Melanchthon, refers to it as *articulus*. Sonnino (1968) and Burton (2007) provide full details of terminology and definition for this and other rhetorical figures.

[16]The page between pages 131 and 133 in Peacham's text is labeled "128," apparently due to a scribal error.

[17] I have silently modernized the spelling in all quotations from Peacham and Puttenham.

[18] Though Fahnestock (2002 and 2011) mentions the figure that I am here calling congeries and briefly discusses its nature and relationship with other, similar figures, she nowhere discusses its possible role in invention.

individual act of imaginative apprehension" (563). By listing diverse elements of the same sort, then, congeries allows a rhetor to invoke a concept, even if the concept does not currently exist and must be derived from the list itself. The theologian Paul Tillich (1973), for example, uses congeries in this way when describing how scientific and bureaucratic ways of thinking and understanding reality—"controlling knowledge," as he collectively refers to them—dehumanize us: "Man actually has become what controlling knowledge considers him to be, [i] a thing among things, [ii] a cog in the dominating machine of production and consumption, [iii] a dehumanized object of tyranny or [iv] a normalized object of public communications" (99). Though Tillich does not specify what all these phrases have in common, the category which they construct is nevertheless clear to the reader—as is the evaluation of controlling knowledge which Tillich is trying to transmit to the reader by way of this use of congeries.

Darwin's use of congeries as an investigative device was not intended to present a concept or a valuation to an audience: rather, Darwin's congeries were intended to gather hitherto scattered observations about nature in a way that suggests some underlying explanation, concept, or regularity. This investigative use of list-making appears to have derived ultimately from Francis Bacon. Bacon saw as the first step in scientific investigation the collection of instances of the phenomenon being investigated—that is, the making of a list. In his *Novum Organum*, Bacon suggests that the investigation of nature should start with the amassing of particular perceptions of the natural phenomenon being investigated: "we must first of all have a muster or presentation before the understanding of all known instances which *agree in the same nature, though in substances the most unlike*" (II.11; emphasis added). With this comprehensive and heterogeneous "presentation of instances to the understanding," the scientific investigator can find patterns in the various appearances of the phenomenon in question, even though these appearances seem, at first sight, to be impossibly diverse (II.15). Taking heat as his example, Bacon models the investigative process with a 27-item list of “Instances Agreeing in the Nature of Heat,” including “the rays of the sun, especially in summer and at noon,” “all flame,” “all bodies rubbed violently,” and “quicklime sprinkled with water” (II.11). Eventually, this list, combined with other methods, allows the naturalist to hypothesize about the fundamental nature or form underlying these diverse manifestations of, e.g., heat. In particular, the investigator can generate new claims about the phenomenon being investigated by finding “such a nature as is always present or absent with the given nature, and always increases and decreases with it” (II.15). In the case of heat, for example—whether produced by chemical reaction, flame, or boiling water—we always find motion present; when there is no motion, there is no heat. As with a congeries presented to an audience, then, Bacon’s “presentation of instances to the understanding” collects heterogeneous instances of the same phenomena. The same cognitive process which allows a message recipient to move from a written or spoken congeries to its superordinate concept is employed by the scientific investigator to derive from this Baconian list some underlying concept or regularity which may then be further elaborated upon, investigated, and so on.[19]

In his 1831 book *A Preliminary Discourse on the Study of Natural Philosophy*, Herschel borrows Bacon’s approach to the investigation of nature. Darwin read this book at least twice,[20] and he claimed to be more strongly influenced by this book than by any other book except

[19] Of course, Bacon’s inductive procedure as described in the *New Organon* does not end with the tables of presentation, but continues through many further steps. These particulars, while fascinating, are beyond the scope of the current project.

[20] We know that Darwin first read this book in February 1831 because of a letter sent on February 15, 1831 in which he tells his cousin William Fox Darwin “If you have not read Herschel in Lardners [Cyclopedia] —read it directly.” (All references to Darwin’s letters are to Burkhardt and Smith’s (1985-2013) collection of Darwin’s correspondence.) Darwin read the book again in October 1838 according to his “Books Read” notebook (4v; reproduced with original pagination in Burkhardt and Smith, vol. IV, 433-573).

possibly Humboldt's *Personal Narrative* (Darwin 1958, 67-68; Gildenhuys 594). This influence is apparent in Darwin's terminology and methodology in the transmutation notebooks and after. Darwin's treatment of analogical *vera causa* arguments, for example, is distinctively and unmistakably Herschelian (Gildenhuys 2004; Ruse 1975; Sloan 2003). Given Darwin's respect for and familiarity with this text, and the methodological borrowings which he made of it in other areas, it is reasonable to suppose that Darwin's investigative list-making was adapted from Herschel, as well.

Herschel's methodology, like Bacon's, begins with the listing of instances of the natural phenomenon under investigation. These instances should be both numerous and heterogeneous: "the more different these collected facts are in all other circumstances but that which forms the subject of enquiry, the better; because they are then in some sort brought into contrast with one another in their points of disagreement, and thus tend to render those in which they agree more prominent and striking" (119). As with Bacon's list-making, the scientific investigator attempts to produce a list of examples that is as large and as heterogeneous as possible. Once generated, this list is, as in Bacon's method, interrogated for some underlying similarity useful in the generation of scientific knowledge: once we have generated "a deliberate assemblage of all the parallel instances we can muster," we may then "search among the individuals of this class for some other common points of agreement, among which the cause [of the phenomenon] will of necessity be found" (150). Thus, in Bacon's and Herschel's methodology, and in Darwin's, as will be shown shortly, the listing of heterogeneous items allows the investigator to probe for some shared similarity among these items other than the similarity used to compile the list. This novel similarity, once found, is a candidate for a novel theoretical entity, relationship, or natural law. The list-making procedure adapted by Darwin from his predecessors, then, involves gathering together previously scattered knowledge into a single knowledge representation useful in generating novel insight.

Congeries as an Argumentative Tool

The investigative congeries in Darwin's notebooks are plain and emotionless. To preview an example analyzed in detail in the next section, Darwin provides in his Red Notebook a list of mammals which have been introduced into foreign environments and which have outperformed the indigenous animals already there: "Dogs. Cats. Horses. Cattle. Goat. Asses. have all run wild & bred. no doubt with perfect success" (133). The list has no detail, no pathos, and is merely a tool for developing novel insights. But Darwin also uses lists in his published writings, and these lists have a very different character. Frequently, these lists involve pathos very strongly, and are sometimes among the most passionate elements in the text. In *On the Origin of Species* (1859), for example, Darwin uses a number of such lists to foreground the explanatory power of his theory, or to attack the explanatory power and likelihood of special creationism. In one such list, Darwin demands to know how the traits of certain peculiar bird species could possibly be explained on a creationist account:

> How strange it is that a bird, under the form of woodpecker, should have been created to prey on insects on the ground; that upland geese, which never or rarely swim, should have been created with webbed feet; that a thrush should have been created to dive and feed on sub-aquatic insects; and that a petrel should have been created with habits and structure fitting it for the life of an auk or grebe! . . . . But on the view of each species constantly trying to increase in number, with natural

> selection always ready to adapt the slowly varying descendants of each to any unoccupied or ill-occupied place in nature, these facts cease to be strange, or perhaps might even have been anticipated. (471-72)

Darwin uses congeries, insistent repetition of the phrase “should have been created,” and syntactical parallelism to increase the vehemence of this list, underlining the force of these bird species in contradicting a creationist account. Thus, while lists in the notebooks seem to be investigative in nature, the lists in Darwin’s published writings seem instead to be means of persuasion. Darwin is not here trying to develop an insight into what these different birds have in common, but is instead trying to impress upon readers the vast array of natural facts which are incomprehensible from a creationist perspective and unsurprising from an evolutionary one.

Darwin’s presentational use of lists is best understood in terms of congeries. Both the investigative congeries of Bacon and Herschel and presentational congeries share similar syntax and a similar conceptual function: in each case, the listed items, in spite of their variety, all belong to some superordinate category which the list evokes. However, presentational congeries do rhetorical work that investigative lists do not: specifically, they provide *amplification*. Following Quintilian (8.4. *passim*), Peacham describes amplification in rhetoric as “a certain affirmation very great and weighty, which by large and plentiful speech moveth the minds of hearers, and causeth them to believe that which is said” (120). Fahnestock describes amplification of a particular subject as a means of endowing that subject “with stylistic prominence so that it acquires conceptual importance in the discourse and salience in the minds of the audience” (2011, 390). By saying more things about the same topic, the topic’s perceived significance is increased. Moreover, amplification allows a rhetor to praise or condemn the subject of discourse, and to move the audience “to be on his side. . ., to mourn or to marvel, to love or to hate, to be pleased or to be angry, to desire or to be satisfied, to fear or to hope," and so on (Peacham 121; note that this list uses congeries for amplification). For this reason, figures like congeries which involve amplification are best applied to "whatsoever is commendable, and do merit high praise, or abominable and deserveth punishment" (122). Darwin's list of introduced mammals in the Red Notebook provides no such amplification, and does no praising or blaming. His list of birds in the *Origin*, on the other hand, 1) increases the perceived importance and salience of what is being listed by using a lot of words to list it; 2) forcefully foregrounds the inadequacy of creationism by providing a lengthy list of phenomena utterly inexplicable on a creationist account; and 3) gives readers a sense that the theory which can explain such a varied and large group of observations is impressive and desirable.

In the next two sections, we will trace two of Darwin's lists from early notebook entries to finished theory-presentations. We will see that in both cases, an investigative congeries along the lines set down by Bacon and Herschel—a cross-modal perspectivization—starts the process, and provides Darwin with some novel theoretical insight. But Darwin gains, in addition to this insight, the list itself. Over time, Darwin further refines and elaborates upon this list, allowing it to gain novel rhetorical features which it did not have before. The list understood as a cross-modal perspectivization for generating insight thus becomes a particular set of sentences of discursive prose—sentences which provide important rhetorical features to Darwin's theory presentation. The cross-modal perspectivization governing Darwin's list-making invention thus begins as an investigative resource and ends as a piece of finished prose which performs important rhetorical work involving the emotions and values of his readers.

Darwin's Use of Congeries: Introduced Mammals

As Darwin was beginning the evolutionary speculations of the B Notebook, he was also preparing an account of his *Beagle* voyage for general readers, ultimately published in 1839. In preparing this text, Darwin had the opportunity to go back through his observations on the voyage in a methodical way. One particular class of observations seemed especially prominent and puzzling to him: the observation that mammals could be brought to a new habitat, one not at all the same as their original habitat, and could actually displace the living things already there. In Buenos Aires, for example, he noted that "The countless herds of horses, cattle, and sheep" brought previously by European colonists "not only have altered the whole aspect of the vegetation, but they have almost banished the guanaco, deer, and ostrich" (1839, 139). Horses, cattle, and rabbits abounded on the Falkland Islands (248-49). And on the island of St. Helena in the South Atlantic, the goats first introduced in 1502 had so rapidly overtaken the island that by 1731, Darwin learned, an order was issued that all stray goats should be killed (172). Thus, animals introduced from elsewhere could sometimes overtake a habitat, even displacing indigenous animals.

This would have seemed strange to Darwin. According to the creationism which he shared at this time with theologians like William Paley and naturalists like Georges Cuvier and Charles Lyell, God created each species separately, created it to be a perfect fit for its environment, and created the environment to be a perfect fit for it.[21] But if this is true, then how could European horses and cattle outcompete Argentinian guanacos and ostriches? Nevertheless, Darwin does not address this oddness either in his diaries from the *Beagle* voyage or in the 1839

[21] On this creationism and its relation to Darwin's thought during the notebook period, see Ospovat (1981; 9-15, 33-34) and Richardson (1981; 9-11). Lyell was later to become a transmutationist, i.e., an evolutionist.

description of the voyage. The first textual record I can find of Darwin addressing this difficulty is in a fragmentary passage in the Red Notebook from 1837, sandwiched between a discussion of sexual and asexual reproduction and a discussion of the ability of elephants and rhinos to live in areas with little vegetation. In spite of its fragmentary character, however, and its seeming lack of connection with the notebook entries before and after it, this passage serves as Darwin's attempt to understand the successes of introduced mammals over their aboriginal rivals: "Dogs. Cats. Horses. Cattle. Goat. Asses. have all run wild & bred. no doubt with perfect success" (133). This rapid, seemingly unplanned list of organisms which have "run wild" provides Darwin with a conclusion: "non Creation [bears upon] adaptation of animals" (133). Darwin's brevity, and the lack of connection to prior and subsequent notebook entries, makes interpretation difficult: it seems, however, that Darwin's list of introduced mammals suggests to him that creationism is not a likely explanation for the fittedness of living things for their habitats, and that another explanation must be sought instead. In drawing upon his memories if these different animals and their habitats, as well as the notebook entries which he is using in the preparation for his 1839 account of the voyage, Darwin gathers together previously scattered knowledge into a single list. This list, in turn, suggests to him the inadequacy of a creationist account of the biogeographical facts.

This interpretation of Darwin's Red Notebook list is supported by a later version of the same list. This version was part of the 1844 *Essay*, a work which Darwin prepared to present his evolution theory to other naturalists in case he died before completing a more polished account. In the section in which Darwin presents his revised list, he is describing facts about the geographical distributions of living things which cannot be explained by creationistic accounts. He introduces his congeries with a question: "Why on the theory of absolute creations," Darwin asks, “should not one island. . . in the open ocean possess a mammiferous quadruped?” (172). Darwin immediately follows this surprising fact about the geographical distribution of mammals by responding to a possible objection: perhaps islands can’t support quadrupedal mammals.

> Let it not be said that quadrupeds cannot live in islands, for we know that cattle, horses and pigs during a long period have run wild in the West Indian and Falkland Islands; pigs at St Helena; goats at Tahiti; asses in the Canary Islands; dogs in Cuba; cats at Ascension; rabbits at Madeira and the Falklands; monkeys at St Iago and the Mauritius; even elephants during a long time in one of the very small Sooloo Islands; and European mice on very many of the smallest islands far from the habitations of man. (1844, 172)

This list is more detailed, of course, than the notebook list: “Goat,” for example, is replaced with “goats at Tahiti,” while monkeys, elephants, and mice have been added to the list. Further, by providing a variety of place-names, Darwin underlines how widespread this phenomenon is: it is found in both the northern and the southern hemispheres, and it is found in islands in the Atlantic, Pacific, and Indian Oceans. Not only *can* mammals live on islands, but an enormous variety of different kinds of introduced mammals thrive on islands all over the world. But though there is no barrier to mammalian quadrupeds living on islands, we do not find any which are endemic to an island. Darwin’s amplification of the previous list—the addition of place names and list items—drives home how widespread this seemingly inexplicable phenomenon actually is.

The Red Notebook list allowed Darwin to find one particular insight: that an animal's adaptation to its environment is not well explained by divine agency, since introduced organisms sometimes do better in an environment than indigenous ones. But the revised list in the 1844 *Essay* has been repurposed to do a slightly more specific job. Rather than directly showing difficulties with a creationist account, the 1844 list instead responds to an objection which Darwin expects his reader to have: that perhaps islands are not able to support quadrupedal mammals. Thus, in addition to its formal differences—the expansion of individual list items, the addition of list items, and the inclusion of place names—the 1844 list is also used to get at a different insight about nature: islands can support quadrupedal mammals, and currently do so all over the world, but none of those mammals are indigenous to those islands. Once a list is used to generate an insight, then, not only is it subject to formal revision, elaboration, and other processes; it may also be employed to support points other than the point to which it originally gave rise in the mind of the investigator.[22] Darwin's list thus 1) generates novel theoretical insight; 2) becomes subject to elaboration and alteration in later rounds of inventional work; and 3) in revised form, can be repurposed for new rhetorical tasks and inserted directly into finished argumentation. Darwin's introduced mammals list thus carries him from initial insight to presentation of theory, shifting in structure and rhetorical function as the writing process progresses.

[22] In later drafts of his evolution theory—the unfinished book *Natural Selection*, which Darwin (1975) worked on between 1855 and 1858, and *On the Origin of Species* (1859)—Darwin no longer employs his congeries of introduced quadrupedal mammals. Though Darwin does mention in the *Origin* the lack of indigenous land mammals on islands, and the thriving of introduced land mammals there, he does not employ congeries in his argument (393-394).

Darwin’s Use of Congeries II: The Gemmule Concept

In 1868, Darwin published his two-volume work *The Variation of Animals and Plants under Domestication*. At the end of this work, Darwin addressed a difficulty which many reviewers had with the *Origin*: though the book gave good reason to believe that organisms have an inherent tendency to vary in their traits, and though the inheritance of traits played a key role in Darwin’s theory, no account was given of why traits vary, or how they are transmitted on to offspring. Darwin addressed this criticism with a novel theory of how information about traits is stored in the bodies of organisms, and how traits are transmitted to descendants—his so-called *pangenesis* theory. Key to this theory was the idea that throughout the bodies of living things are microscopic entities called *gemmules* which contain heritable information about the organism’s entire body. Darwin generated his gemmule concept with the aid of an investigative list in his third transmutation notebook, the D Notebook. In subsequent iterations of this list, Darwin added to and elaborated upon this notebook list. He also reordered the elements in such a way that the list became an incrementum—that is, Darwin turned an unordered list of heterogeneous phenomena into an ordered list with a clear progression. By revising this list and adapting it to new rhetorical tasks, Darwin took a cross-modal persrpectivization generated along Herschelian and Baconian lines and transformed it into a rhetorical figure emphasizing the relatedness of the phenomena ostensibly explained by the gemmule concept. As with the introduced mammals congeries, then, Darwin’s D Notebook list provides, over several iterations of inventional activity, theoretical insight as well as argumentative prose intended for a scientific audience.

Hodge (1985) has taught us to see Darwin as a “lifelong generation theorist.” From the earliest pages of his first transmutation notebook through the publication of his later works, Darwin was continuously interested in sexual and asexual reproduction, the inheritance of traits, and how these phenomena relate to the environments of organisms. (e.g. B 1ff., E 148). In the D Notebook, for example, Darwin is probing the nature of asexual reproduction in plants. Several of the pages immediately before this discussion have been lost, so it is not certain exactly how Darwin began to examine the budding of plants.[23] But whatever the motivation that led Darwin to this examination, he begins it with an assertion by a horticulturalist named Conrad Loddiges: roses are able to transmit traits more easily through budding than through seeds (128). This assertion leads Darwin to an obvious question: how are budding and sexual reproduction in plants different? To better understand asexual reproduction in plants, Darwin constructs a list of phenomena which seem similar to budding: "Bud probably is like cutting off tail of Planaria, the whole grown to that part.—claw added to crab, tail to lizard,—healing of wound" (129). Having produced this congeries, he next derives the superordinate concept presented by the series: "in the separated part every element of the living body is present. . . . *On this view each particle of animal must have structure of whole comprehended in itself. — it must have the knowledge how to grow & therefore to repair*" (129-130, emphasis added). The superordinate concept generated with the aid of the "budding" congeries, then, is that there must be representation of missing or not-yet-formed parts in the tissues of the body currently in existence, such that *each part* of an organism's body contains information about the body *as a whole*. The possible value of this new notion, appearing for the first time in this D Notebook passage, is immediately clear to Darwin: "That the embryo the *thousandth* of inch should produce a Newton is often thought wonderful, [but] it is part of same class of facts, that the skin grows over a wound" (130-31). A natural phenomenon which is easily observed, everyday, and not particularly mysterious belongs to the same class of phenomena as the mysterious creation of a brilliant adult from a microscopic

[23] Pages 119-126 are missing from the D Notebook. Page 127 provides an apparently unrelated discussion about the inheritance of color in wild dogs. The passage analyzed here begins on the following page.

clump of cells—and all the phenomena in this class, somehow, are governed by the fact that information about an organism's entire body is found in every separate part of that body.

Darwin continued to develop this notion of each body part containing information about the whole body over the next two decades, until he had constructed a theory employing the gemmule concept to explain how organisms inherit and pass on traits, and how phenomena like budding and regeneration could occur—his theory of pangenesis.[24] Basically, Darwin believed that each cell of an organism's body is continuously throwing off numerous microscopic particles, called gemmules, each of which contains information about the part of the body from which it originated. These gemmules, in turn, tend to congregate together, whether at the stump of a crab's amputated claw or in the bud of a plant. It is the information from these gemmules which allows a lizard's absent tail to be rebuilt accurately, or a planarian worm cut in half to become two new worms. In addition to explaining the inheritance of traits, then, Darwin's gemmule concept, and the larger pangenesis theory of which it was part, was intended to explain a wide variety of natural phenomena, from trait inheritance to the healing of injuries.

In 1865, Darwin prepared a short manuscript outlining this theory and sent it to T. H. Huxley.[25] In this manuscript, we see Darwin presenting a revised version of his D Notebook budding congeries. This revision, in addition to more polished language, involves two important innovations. The first is that Darwin adds sexual reproduction to the list. Partly as a result of investigations by Johannes Müller and T.H. Huxley on parthenogenesis and related phenomena in the 1840s and 1850s, Darwin had come to see the fertilization of eggs in sexual reproduction

[24] For a fuller discussion of how Darwin developed his overall pangenesis theory, see Olby (1963), Geison (1969), Hodge (1985), and Browne (2002).

[25] The document believed to be Darwin's original draft of this pangenesis manuscript is transcribed in Olby (1963). In his presentation of this manuscript, Olby provides the manuscript's original pagination, which I use below.

as similar to self-fertilization in parthenogenetic and budding organisms (Darwin 1865, 36-37).[26] The second important difference between Darwin's original notebook list and the pangenesis manuscript list is that the order of the list has changed. Having derived from his original congeries the idea that all the listed phenomena require information about the organism's entire body to be contained in each part, Darwin has realized that the items on the list differ in the *amount* of the organism's body which must be reconstituted: in a scab healing over a wound, the amount is very slight; in regeneration, the amount is somewhat larger; and in budding, an entirely new body must be produced. Rather than reproducing his congeries, then, Darwin makes use of incrementum in the 1865 manuscript, such that his list has directionality. I have added Roman numerals to this incrementum for clarity: "[i] True seminal generation [i.e., sexual reproduction] passes by a not much broken series, through [ii] gemmation or multiplication by buds, through [iii] fissiparous generation [e.g., the ability of a planarian worm cut in half to produce two new organisms] and [iv] the renewal by growth of large portions of mutilated individuals, into v) simple continual growth" (36). As Fahnestock notes, an incrementum can be used to "dissolve differences between categories and so reconfigure a conceptual domain, replacing differences in kind *between* categories by differences in degree *within a new larger category* (2002, 97, emphasis added). The "new larger category" is the same category governing Darwin's original D Notebook congeries, namely, phenomena related to budding in plants. But in order to present this category to readers, he orders the list in such a way that the great similarity between adjacent items suggests their underlying identity. From the creation of a new organism by the combination of gametes to budding to regeneration to day-by-day growth, Darwin uses incrementum to plot a trajectory from organic processes which require an entire

[26] A parallel passage describing and arguing for the fundamental similarity of sexual and asexual reproduction occurs in Darwin (1868, 359-364). For further details on this important shift in Darwin's thinking on sexual reproduction, see Olby 1985.

organism to be created from nearly nothing to the everyday process whereby an organism gets larger during the course of lifespan development. As different as scab formation may appear from the sexual reproduction of animals, both are governed by the same logic, a logic which Darwin's pangenesis theory proposes to lay out.

Having received some dispiriting criticism of his pangenesis manuscript from Huxley (now unfortunately lost),[27] Darwin was careful in his first published discussion of pangenesis to position it as a "provisional hypothesis" (1868, 357). Darwin presented this hypothesis at the end of the second volume of his *Variation of Animals and Plants under Domestication* (357-405). This positioning was very useful for Darwin: it meant that he could introduce many of the reproductive phenomena ostensibly explained by his theory in previous chapters, describing their relationship to variation in traits, natural and artificial selection, and other factors. While discussing in detail natural phenomena like budding and limb regeneration in these previous chapters, Darwin could also prepare the way for the presentation of his pangenesis theory at the end of the book. Thus, more than sixty pages before introducing pangenesis, Darwin is able, in a discussion about the "co-ordinating and reparative power" of various organisms, to present elements of his original notebook congeries, albeit in a more expanded form:

> Blumenbach and others have insisted that the principle which permits a Hydra, when cut into fragments, *to develop itself into two or more perfect animals*, is the same with that which causes a wound in the higher animals *to heal by a cicatrice* [i.e., a scab]. Such cases as that of the Hydra are evidently analogous with the spontaneous division or *fissiparous generation* of the lowest animals, and

[27] See Darwin's letters to Huxley dated 30 May 1865 and 12 July 1865.

> likewise with the *budding of plants*. Between these extreme cases and that of a mere cicatrice we have every gradation. (293-94, emphasis added)

This treatment does not mass the phenomena being discussed in a congeries, or order them in an incrementum. Rather, each element is related to one or more other elements across several sentences using connections like "is the same with" and "are evidently analogous with." For many of the connections among these phenomena, Darwin provides reasons, or refers to the reader's existing knowledge to warrant the connection. Thus, the hydra's ability to be split is like the formation of scabs, *according to Blumenbach*; the hydra's splitting is "evidently analogous" with the similar splitting of "the lowest animals" (e.g., planarian worms), apparently since both involve an organism split in half becoming two distinct organisms. Darwin has introduced the phenomena which his pangenesis theory is meant to explain, and has begun to set up the connections among these phenomena.

When Darwin finally begins his presentation of pangenesis, he can revisit these earlier phenomena, once again using incrementum to underline their similarity to one another and their membership in a larger, novel category. This category—phenomena only explicable if we assume that each part of an organism's body contains gemmules—will obviously be new to readers. To make this novel category seem a plausible addition to already familiar scientific categories, Darwin returns to the natural phenomena already introduced previously. Before presenting his incrementum, Darwin first has some preparatory work to perform. He first forecasts the overarching logic of this incrementum for his readers: "Between the production, by fissiparous generation, of two or more complete individuals, and the repair of even a very slight injury, we have, as remarked in a former chapter, so perfect and insensible a gradation, that it is impossible to doubt that they are connected processes" (359). Darwin then uses the authority of another naturalist, James Paget, to strengthen one of the connections which he will need for this incrementum, the connection between embryonic growth and the healing of injuries:

> As at each stage of growth an amputated part is replaced by one in the same state of development, we must likewise follow Mr. [James] Paget in admitting "that the powers of development from the embryo are identical with those exercised for the restoration from injuries: in other words, that the powers are the same by which perfection is first achieved, and by which, when lost, it is recovered." (359)

Having prepared the way for an incrementum with the aid of Paget and, earlier in the text, Blumenbach, Darwin now presents it in a single sentence. I have again added roman numerals for clarity:

> Finally, we may conclude that [i] the several forms of *gemmation* [i.e., budding], and of [ii] fissiparous generation, [iii]the repair of injuries, [iv] the maintenance of each part in its proper state, and [v] the growth or progressive development of the whole structure of the embryo, are all essentially the results of one and the same great power. (359)

As in the 1865 pangenesis manuscript sent to Huxley, the elements of the original D 129 congeries are here presented in order from processes which require an entire organism’s body to be created to processes which only require regeneration of a part to processes which involve mere growth. Further, insofar as all these heterogeneous processes are made to appear closely related with the aid of this incrementum, they are also presented as results of “one and the same great power.” Thanks to the amplifying power of incrementum, the sheer number and range of phenomena owing their existence to this power increase its perceived importance. This, in turn, makes any theory which can deal adequately with this “power” likely to be more interesting to readers.

Two important revisions to this incrementum, however, reflect Darwin’s changing rhetorical strategy since the manuscript which he sent to Huxley. After Huxley’s dispiriting criticism in 1865, Darwin knows that he needs a stronger case for his theory. Thus, just as he cited Blumenbach’s authority for the identification of wound healing and the “fissiparous generation” of the hydra, he here cites Paget’s authority for the identification of embryonic growth and the healing of injuries. Second, sexual generation has again disappeared. This incrementum only unites growth, healing, and asexual reproduction. But shortly after this incrementum, Darwin dedicates the entire next section of this chapter to the identification of sexual and asexual reproduction, a section in which he relies upon eight different naturalists to justify this identification (359-364). Only after this careful attempt to show that sexual and asexual reproduction are not as dissimilar as they first appear does Darwin again present an incrementum of modes of asexual reproduction, this time sandwiching the incrementum between two assertions that sexual and asexual reproduction differ in degree and not kind:

> From the several foregoing considerations we may conclude that the difference between sexual and asexual generation is not nearly so great as it at first appears; and we have already seen that there is the closest agreement between [i] gemmation, [ii] fissiparous generation, [iii] the repair of injuries, and [iv] ordinary growth or development [end of list]. The capacity of fertilisation by the male element seems to be the chief distinction between an ovule and a bud; and this capacity is not invariably brought into action, as in the cases of parthenogenetic reproduction. (362).

The ordering of elements is identical to that of the 1865 incrementum, with the exception that sexual reproduction has been changed from a list item among others to a way of introducing and concluding the list. Darwin has thus set up a series of phenomena which his theory is ostensibly able to explain: sexual reproduction, parthenogetic reproduction, budding, “fissiparous generation,” healing, and ordinary growth. Having prepared the reader to accept all these diverse phenomena as belonging to a series, and thus to a single, overarching category of natural phenomena, he is now in a position to present the theory intended to explain this category of phenomena. Further, having repeatedly used the amplifying power of incrementum to emphasize the immense variety of these phenomena, he has also suggested that the theory able to explain them all has impressive explanatory power indeed. Having prepared the ground, Darwin now presents the theory itself (374-402).

Darwin began in the D Notebook by developing an early version of his gemmule concept, realizing that budding, fissiparous generation, and healing all require that information about an organism’s entire body must be found in each part of that body. In the 1865 manuscript, Darwin reorders this list into an incrementum, thus emphasizing the close similarity of adjacent list items and making their mutual belonging to an overarching category more plausible. He also adds sexual reproduction to the list, increasing the range of phenomena ostensibly explained by his theory. In light of harsh feedback from Huxley, Darwin realizes that for his 1868 published presentation, more work is needed to show the connections among the phenomena on his list. The incrementum then becomes, not just a list of phenomena explained by the theory, but a rhetorical goal: Darwin realizes that the incrementum must be set up beforehand with the use of authoritative claims by naturalists like Blumenbach and Paget, and with extensive argumentation. In the incrementums of 1868, the amplifying power of the figure emphasizes the impressive explanatory power of the theory which he is about to present to his readers. In short, Darwin's D Notebook congeries begins as an investigative tool, is revised as an incrementum suggesting the underlying unity of the natural phenomena with which the pangenesis theory deals, and ends in 1868 as a structuring principle which constrains decisions about earlier portions of the text—how the writings of other naturalists are used, how the different phenomena on the list are argued into proximity with one another, and so on. For Darwin, then, the D Notebook list becomes an resource which can be revised according to rhetorical constraints in light of the inadequacies of previous iterations.

Conclusion

We have seen Darwin use lists for invention in two ways. In developing theoretical innovation, Darwin follows the technique suggested by Herschel and Bacon, massing natural phenomena which appear similar. By bringing together previously scattered knowledge into a single representation, Darwin can then derive from this list a hitherto unconsidered similarity shared by the listed items. This shared similarity thus becomes a candidate for further inventional elaboration. Thus, by listing introduced mammals which have outcompeted indigenous animals, Darwin comes to realize that creationist accounts of why animals fit their environments well are not effective. By listing natural phenomena which seem similar to budding, Darwin arrives at the idea that each part of an organism's body must contain information about the entirety of the organism's body.

When Darwin uses a list as an investigative tool in his notebooks, he thus gains an insight, which may then be revised and elaborated upon until it can pass muster as a plausible fact about nature worth communicating to a scientific audience. He has also, however, developed the list itself, a cross-modal perspectivization which can *also* be revised and elaborated upon, thereby creating argumentation. The list itself, in short, is not cast aside once it has fulfilled its investigative purpose, but rather continues to serve as a rhetorical resource in subsequent rounds of revision. The list may be repurposed for a different rhetorical end, as when Darwin uses the introduced mammal congeries to answer the objection that quadrupedal mammals might not be able to live on islands in the open sea. Alternately, items may be added to the list, and each list item may be elaborated upon, as when Darwin adds place-names and new examples of introduced mammals to his original notebook congeries. Further, the list may be reordered as an incrementum, allowing it to do rhetorical work which it could not perform as a (non-directional) congeries. Thus, by ordering budding, fissiparous generation, healing, and growth in a trajectory, Darwin can make the commonality of these natural phenomena seem more obvious, such that the step from one listed phenomenon to the next seems slight, suggesting that all listed phenomena might be explicable with a single theory. Similarly, when Darwin revises his aboriginal species list, he adds species and says more about each species, adding amplification to what was simply an inventionally useful inventory.

Further, the list may provide, not just a single congeries or incrementum which can be inserted into a published text, but also a comprehensive rhetorical strategy. Thus, in moving from his 1865 pangenesis manuscript to the finished 1868 presentation of his theory, Darwin treats the ultimate incrementum from sexual reproduction to the healing of minor wounds as a sort of rhetorical destination, and uses work by Paget, Blumenbach, and others to prepare the way for this destination. Darwin’s lists, then, begin as tools for discovering novel insights into nature; in their further elaboration, revision, and reordering, they become pieces of finished argumentative prose; and during this revision process, the rhetorical goals and dynamics of the list may be altered so as to optimize their effectiveness for the text which Darwin is constructing for the presentation of new theory. Viewed as a revisable knowledge representation useful for invention, then, Darwin's lists provide novel theoretical insight, novel argumentative prose, and novel argumentative strategy. From the most abstract relationships among scientific concepts to specific decisions about word order to the overarching rhetorical strategy governing a long stretch of text, Darwin's lists guide the processes of generating and presenting theoretical innovation from beginning to end.

Chapter Three

Visual Invention

> It is, therefore, a very extraordinary feature of Diagrams that they *show*,—as literally *show* as a Percept shows the Perceptual Judgment to be true,—that a consequence does follow, and more marvelous yet, that it *would* follow under all varieties of circumstances accompanying the premisses. It is not, however, the statical Diagram icon that directly shows this; but the Diagram-icon having been constructed with an Intention. . . .
>
> --C. S. Pierce, qtd. in Stjernfelt 2000 (362)

By the summer of 1837, Darwin had become convinced that the history of life on earth must be an evolutionary history, and he had begun attempting to determine the mechanisms of evolutionary change. One tool which he used in this investigation was diagrams. In the B Notebook, Darwin produced a series of three genealogical diagrams, formally similar to family trees, the first of which is presented in Figure 3.1. Having developed his evolutionary insights over the next 22 years, Darwin published them in his 1859 book *On the Origin of Species*. That book features only one illustration: again, a family tree diagram meant to show evolutionary and taxonomic relationships among various groups (taxa) of organisms. But while the 1837 tree diagrams in the B Notebook were crude, hastily sketched affairs intended only to help Darwin think through his theory, the 1859 tree diagram in the *Origin* was much more sophisticated. First, instead of being used as a way for Darwin to develop theoretical insights, it was designed to make Darwin's theory credible for an audience. Second, in addition to visual conventions typical of family trees, Darwin's published diagram also employed visual conventions from geometry, with these different visual conventions being combined into a single rhetorical whole. Third, and most impressively, Darwin's tree diagram was not merely intended to depict something or to argue for one particular assertion or set of assertions. Rather, Darwin's single diagram was involved in half a dozen visual-verbal arguments scattered throughout the text of the *Origin*. Scholars in rhetoric who deal with visual-verbal argumentation and invention have said a great deal about the role of visuals in scientific invention. However, this gradual building of a visual capable of grounding several distinct multimodal arguments has not been addressed by previous scholarship.

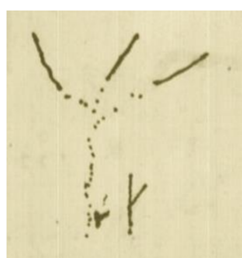

Figure 3.1: Darwin's first B Notebook tree diagram (26).

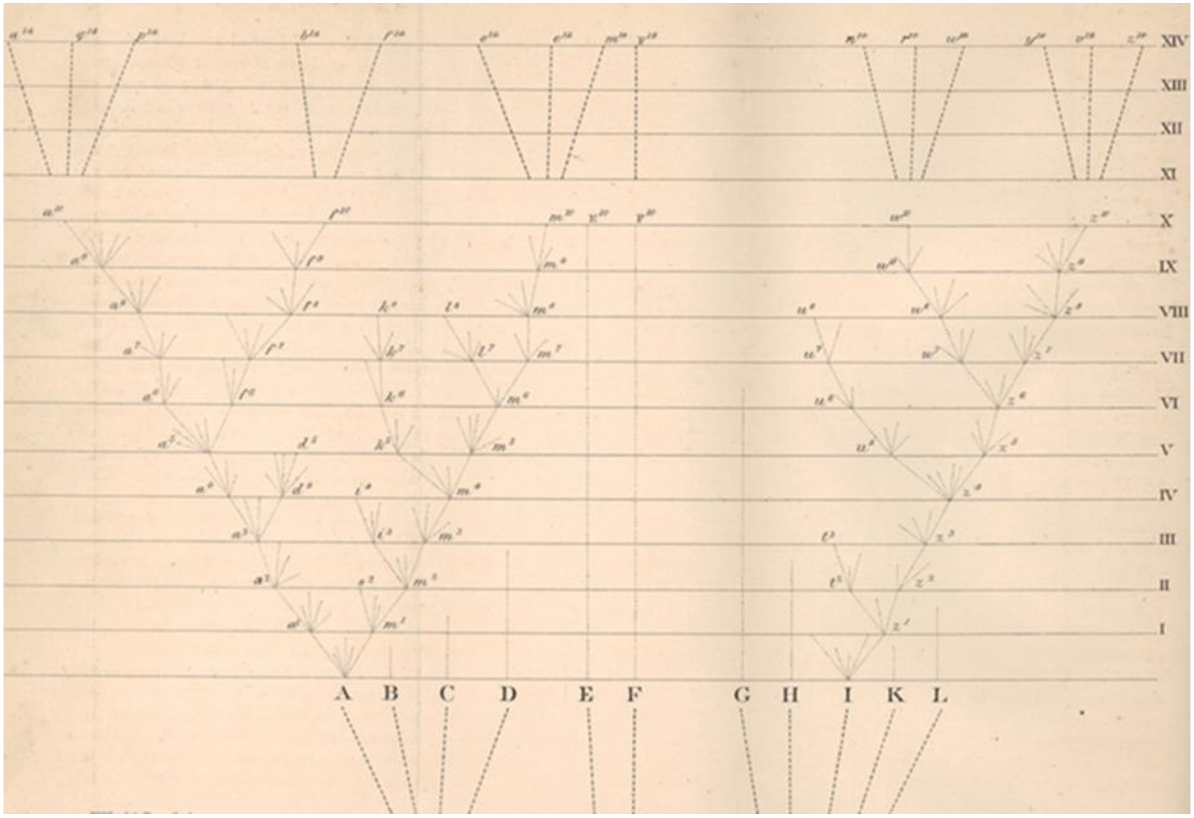

Figure 3.2: Darwin's tree diagram from *On the Origin of Species* (facing p. 117).

In this chapter, I begin by examining what scholars of rhetoric have said about the role of visual elements in theory-generation and rhetorical invention. I then use the insights from these discussions to analyze Darwin's theoretical and rhetorical innovation, first in 1837 in the B notebook, then in the early and middle 1850s, and finally in the finished presentation of his theory in *On the Origin of Species* in 1859. In the early stages of this inventional work, I show how Darwin used his tree diagrams to develop novel theoretical claims, novel representational practices, and novel reasoning strategies, and on how these interacted both with each other and with Darwin's existing knowledge about nature. In short, Darwin's early visual-verbal invention provides him with new assertions about nature, and new ways of representing and thinking about those assertions. In the later stages of this inventional work, I concentrate on how both Darwin's representational practices and his overall visual-verbal rhetorical strategy co-evolved, so to speak, until the finished presentation of his theory in 1859. I hope to show through this diachronic analysis of Darwin's visual-verbal invention how, beginning with simple family-tree diagrams which provided him with novel theoretical insights, Darwin was able to gradually build, over the course of a two-decades-long process of iterative rhetorical invention, a diagram with extraordinary rhetorical capacity which could serve as the central pillar of the published presentation of his theory.

The Role of Visuals in Scientific Invention

The central place of visuals in the development and presentation of Darwin's evolution theory is frequently remarked by scholars in the history and rhetoric of science, as is the importance of visuals in publicizing and elaborating upon Darwin's theory in later decades.[28] More generally, the place of visual elements in scientific persuasion has received a great deal of recent scholarly attention within rhetoric and related disciplines.[29] One aspect of visual-verbal argumentation in science which not received very much attention, however, is the role which diagrams, sketches, and other visual elements play in invention. Outside the rhetoric of science, there has been some work on visual rhetorical invention, such as Medhurst and Desousa's (1981) discussion of the topoi used in editorial cartoons, or Kostelnick and Hassett's (2003) treatment of the various rhetorical dynamics, including inventional ones, involved in visual conventions. By

[28] See, e.g., Brink-Roby (2009), Voss (2010), Talasek, Welch, and Fineman (2011), Archibald (2012), and Pietsch (2012).

[29] E.g., Baigre (1996), Dombrowksi (2003), Richards (2003), Pauwels (2006), Jack (2009), and Gross and Harmon (2014).

and large, however, the role of visuals in rhetorical invention, especially in science, has received surprisingly little sustained attention (Portewig 2008, 334; Northcut 2011, 307). The scholarly work which has been done on visual-verbal rhetorical invention in science has, for the most part, dealt with the following issues: first, the inventional constraints governing the generation of visuals themselves; second, the place of these visuals in the larger writing processes of scientists, engineers, and other technical communicators; and third, the epistemic and investigative functions carried out by visuals in the inventional practice of scientists. Though this scholarship has provided varied and important insight into the role of visuals in scientific invention, I will argue that it neglects an aspect of invention that is essential to Darwin's practice: the development through time of a progressively more rhetorically complicated knowledge representation.

Portewig (2008) and Northcut (2011) concentrate their attention on the constraints which govern the generation of visuals in scientific and technical communication. Portewig studies the "visual rhetorical invention" of twelve technical communicators at three corporations in order to examine "how visuals such as charts, graphs, diagrams, photographs, and screenshots get incorporated into technical documents in the workplace" (333). She notes four factors involved in the creation of visuals in the workplace and their incorporation into technical documents: conventional factors related to the company's communicative norms, genre conventions; and the like; technical factors relating to the level of training and comfort with visual software and related issues; social dynamics relating to collaboration with engineers, the communicator's role in the organization, and so on; and factors relating to resources (time, budget, etc.; 339ff.). Similarly, Northcut studies the inventional practices of three paleontology illustrators, examining the constraints which they face in developing visuals (mostly paintings) of extinct animals. She notes that in addition to the client's wishes and the features of prior paleontological illustrations of similar extinct animals, illustrators are also constrained in their invention by "nonscientific social facts," such as the widespread belief among laypersons that *Archaeopteryx* is the ancestor of modern birds, or the depiction of *Tyrannosaurus* as having closely spaced, unbroken, bright white teeth, contrary to what paleontologists now believe to be the case (319-320). Illustrators who fail to work within such social facts are thus "likely to be subject to some penalty" (318). In addition to their concentration on constraints on visual invention, Portewig and Northcut also address a second aspect of visual rhetorical invention: the place of visuals in the larger process of rhetorical invention in scientific and technical communication. Both find, in their separate analyses, that visual invention is not merely a stage carried out at the beginning of the process, but that it rather continues throughout the creation of a piece of communication. Whether deciding where to place a visual in a corporate document or how to depict a particular dinosaur, inventional choices continue throughout the process of planning and creating visual and visual-verbal communication (Portewig 2008 (337); Northcut 2011 (308)).

Further detail about the place of visuals in invention comes from Walsh and Ross (2015) and Hutto (2007). Both authors agree with Portewig and Northcut that visual invention is not merely limited to the early stages of text production, but both also provide more detail about the inventional process. In a pilot survey of 144 scientists regarding their processes of generating visuals, Walsh and Ross found that many scientists, far from beginning with data or prose, typically begin by creating a visual, using this visual to aid them in the generation of the verbal portion of the text (129). Even more surprising, between 6 and 17 percent of surveyed scientists (depending on their answers to particular questions) invented graphics, not just in the preparation of an article, but to help them with the interpretation of results in their data, before the writing up of those results for publication has even begun (131). Similarly, in his investigation of the visual-verbal invention of fifteen engineers, Hutto found that visual elements could be created either before or during the creation of textual elements. Visual and verbal elements frequently give rise to one another throughout the inventional process (96-97). Indeed, for one of the engineers Hutto studied, “the writing comes last, almost as a kind of documentation of what has preceded it” (88). In their discussions of the place of visuals in the inventional process, then, Portewig, Northcut, Walsh and Ross, and Hutto find that visual invention is carried out throughout the process of document creation, and that visual and verbal elements inform one another throughout this process.

Concentrating on the example of Darwin’s tree diagrams, both in his notebooks and in *On the Origin of Species*, Alan Gross (2006) examines the place of Darwin’s visuals in the larger process of generating and presenting his evolution theory. Like Walsh and Ross and Hutto, Gross finds that visuals appear early in Darwin’s inventional work, toward the beginning of his first notebook dedicated to speculations about evolution, and continue throughout Darwin’s inventional process. Gross sees this inventional process as a movement “from diagrams integral to self-persuasion to those designed for the persuasion of others” (90). In his first transmutation notebook, the B Notebook, Darwin simply borrows a well-entrenched set of visual conventions from family trees in order to represent evolutionary relationships among species, both living and extinct. These hastily sketched family trees make it easier for Darwin to develop insights about these evolutionary relationships. Later, in the single tree diagram in the *Origin*, Darwin combines the conventions of family trees with contemporary scientific conventions used to represent the geological column and the fossils found at various layers within that column (96-97). Because of this, the vertical dimension of the tree diagram may either represent time metaphorically (as in family trees) or it may represent space literally (as with scientific visuals representing the chronological layers of the geological column). The fact that the visual dimension of the diagram does both representational jobs simultaneously gives the impression that Darwin's theory as represented by the diagram explains the arrangement of the fossil record: "The geological column is evidence for the theory of descent; the theory of descent explains the geological column. So interpreted, it may be said, Darwin's diagram *is* his theory, his argument" (97). Gross thus shows that Darwin takes the sketched family trees of his notebook, intended only for his own use, and adds scientific visual conventions which produce a diagram useful for the presentation of his finished theory. According to Gross, then, Darwin's visual-verbal inventional process "begins with a rhetorical transaction within the self and ends in a rhetorical transaction with others" (97).

In contrast to scholars in rhetoric who examine constraints on visual invention, like Portewig and Northcut, or who examine the place of visuals in the larger inventional practices of scientific and technical communicators, like Walsh and Ross, Hutto, and Gross, some scholars have investigated a third aspect of visual-verbal invention in science: the epistemic or investigative aspect. Walsh and Ross touch on this when they note that scientists frequently construct visuals before even beginning to compose an article, as a way to interpret their experimental results, but more detail is brought to this epistemic aspect in a pair of studies by Wickman (2010 and 2013). In these studies, Wickman examines how physicists in the lab use notebooks to record their methods and interpret their results, and how notebook material is later used in the final presentation of work. Wickman (2010) shows that the notebook page is "a constructive resource" because it is a place where various semiotic modes, concepts, and laboratory events come together symbolically in one perceptual location, enabling the scientist to draw useful connections among them (6). In writing a detailed account of his laboratory methodology, for example, one of the physicists whom Wickman (2010) studies turns concrete, physical actions and events in the laboratory into “documentable inscriptions,” inscriptions which in turn “[do] textual work when integrated with other semiotic modes. . . deployed in the same graphic space” (21). This textual work allows documented laboratory events to be related on the notebook page to other elements of scientific practice: chemical processes in the lab which cannot be directly perceived, arguments about the significance and interpretation of laboratory results, and so on. This allows the visual-verbal inscription and interpretation of laboratory events to be developed into patterns of evidence and argumentation useful for later presentation of scientific results. In this way, “the material, technical, and symbolic converge in complex and knowledge-productive ways” in the pages of the lab notebook (2010, 28).

Essential to the movement of meaning from the laboratory to a scientific conference or published article is the visual modality—the various diagrams, digital photographs, and other pictorial elements which share space on the notebook page with descriptions of laboratory method, lists of results, and speculations about future directions for the research: “The technical and the textual converge here through the visual—a convergence which sheds light on the rhetorical construction, interpretation, and circulation of meaning between the laboratory and the display of findings in a public setting” (2013, 153). For example, one set of experiments in the laboratory Wickman studied had as its outcome an “interference fringe” (hereafter referred to as the Fringe) which allowed the scientists to determine how laser light interacted with the sample of material they had produced, and, by extension, how successful the experimental production of that material had been (2013, 158-162). At the end of each trial, the experimental apparatus would produce a particular Fringe, which a physicist would photograph with a digital camera.

This photograph would sometimes be pasted directly into a lab notebook; at other times, hand-drawn sketches of the Fringe would be used; at still other times, a series of Fringes from various experimental trials would be represented in the form of a graph (162-63). These various representations or inscriptions allowed the scientists working in the lab to generate and discuss judgments about the effectiveness of the experimental trial. Further, these representations could give rise to still further "cascades" of representations (Latour 1990), such as further graphs, face-to-face assertions about how the experimental procedure ought to be changed, written assertions about the molecular causes of observed changes in the Fringe, and so on (2013, 162-64). Thus, for these experimenters and their multimodal lab notebooks, the Fringe was

> an object of interpretation that had material presence in the laboratory and could be read against the means of its own production; it was a social object that enabled these scientists to deliberate about the experimental technique being developed; it was an object of representation that could be recorded in a laboratory notebook; and it. . . provided material for generating 'cascades' of inscriptions that in turn could be used to communicate the outcomes of experimental work within and outside the group. (2013, 163)

These 'cascades' of inscriptions—photographs, sketches, graphs, and written sentences—would ultimately generate some of the visual and verbal representations employed in the final presentation of results to other scientists (2013, 163-68). On Wickman's account, then, the interaction among visual elements and verbal elements in a lab notebook allows for the interpretation of experimental results and for the generation of arguments and multimodal representations useful in presenting those results to a scientific audience.

Though he is a historian and philosopher of science rather than a rhetorician, David C. Gooding's (2006) analysis of Faraday's lab notebooks also provides useful insights into the role which visuals can play in the investigation of nature and the interpretation and presentation of experimental results. Gooding examines how Faraday uses notebook diagrams to investigate electromagnetic phenomena and to subsequently present his findings in a rhetorically effective way to his readers. On Gooding's account, Faraday would frequently draw a diagram depicting a phenomenon which he was experimenting with, revising this visual over time. After substantial revision, Faraday would produce a single diagram which could combine observations made in different experimental settings at different times, or to depict the same phenomenon from different perspectives or in different aspects (53-54). Such sketches, subsuming several different experimental trials within a single visual representation, came to be "tools for reasoning with and about phenomena," providing novel insights or suggesting novel avenues of experimental inquiry (59).

In addition, these revised sketches also provided means for communicating Faraday's experimental findings to scientific audiences later on. Thus, a sketch which began as a reasoning tool would subsequently serve as visual evidence in the final presentation of theory: Faraday's sketches begin as "a *cognitive resource* for interpretation and modeling" which was then "crafted into an *epistemic resource* that could provide pictorial evidence for the visual theory constructed from them" (60). Gooding's treatment of Faraday's visual invention thus shows the investigative or epistemic aspect of visual invention in science, and also describes how this aspect continues from Faraday's earliest rough sketches to the polished presentation of finished theory.

Whether investigating constraints on visual invention, the role of visuals in the larger inventional process, or the epistemic and investigative aspects of visual invention, then, scholars in the rhetoric of science and related disciplines have developed an impressive body of insights about how visuals are employed in the development and presentation of scientific knowledge. These scholars show us that visual-verbal invention can begin very early in the process of interpreting lab results or developing theory, and that this invention continues through to final publication. They also show that visuals can serve epistemic as well as persuasive functions; that knowledge representations in visual, verbal, and other modalities inform and give rise to one another, and interact complexly with non-symbolic forms of investigative work; and that visuals may be revised over time to fulfill new functions or to fulfill old functions more effectively. In short, recent scholarship shows that the visual and the verbal interact with one another, and with conceptual and practical aspects of scientific work, at all stages of science, and that visual elements provide insight, suggest avenues for investigation, and generate rhetorically useful ways of presenting material to audiences.

As varied and insightful as this scholarship is, however, it tends to limit its attention to two basic sorts of elements in scientific invention: on the one hand, knowledge representations, especially visual ones, and on the other, scientific claims about nature. Moving from the lab to the writing desk to the published page, recent scholarship shows a variety of complex interactions between these knowledge representations and claims. Left out of this account, however, are the ways in which knowledge representations, claims about nature, and reasoning strategies limit and inform one another through time during the process of scientific invention. Moreover, existing scholarship does not usually trace particular knowledge representations from early notebook stages to the presentation of finished theory in published writing. In this chapter, I hope to show that by tracing knowledge representations from their first appearance in invention up to their final appearance in published theory presentation, we see how knowledge claims, representational practices, and reasoning strategies constrain and inform one another. Still more importantly, as these claims, practices, and strategies come to take on a coherent form ready to present to a scientific audience, scientific invention can take existing knowledge representations and add rhetorical value to them, allowing them to take on persuasive tasks which they would not have been able to do before. By examining the inventional process by which Darwin arrived at the tree diagram in his 1859 *On the Origin of Species*, then, we will see how a single sort of knowledge representation could evolve from a crude thinking aid to a sophisticated component of visual-verbal argumentation to an impressive anchor for half a dozen multimodal arguments scattered throughout a book-length monograph. This inventional process, though lengthy and complex, thus repays the effort involved in its study by showing how knowledge, argumentation, and overarching rhetorical strategy can all emerge over time with the iterative revision of a single type of knowledge representation.

Darwin's Starting Point

In order to understand Darwin's visual-verbal invention in the B Notebook, it is first necessary to understand the beliefs about nature which Darwin held in 1837. Several of these beliefs are no longer held by scientists today, and seem bizarre to modern ears, but Darwin arrived at them on the basis of his education at Edinburgh and Cambridge, and on the basis of observations gathered during his five-year turn as ship's naturalist on board the *Beagle*. This voyage had provided Darwin with a surfeit of paleontological, morphological, and biogeographical observations from around the world. Shortly after his return in October 1836, Darwin began to order these observations into a publishable monograph (Darwin 1839). In the spring of 1837, Darwin also began to theorize about the possibility of species transmutation.[30] In May of that year, Darwin penned his first speculations about evolutionary mechanisms in a handful of pages in a notebook which he had begun during the voyage, the so-called Red Notebook (hereafter abbreviated RN). In summer 1837, Darwin began his first notebook dedicated to transmutation, the B Notebook. In the first two dozen pages of the B Notebook, Darwin further elaborates upon ideas from the Red Notebook, and combines them with insights from previous transmutationist thinkers like Lamarck and Darwin's own grandfather Erasmus Darwin (Kohn 1980; Hodge and Radick 2003; Crick 2005).

Examining Darwin's early speculations on transmutation in the Red Notebook and at the beginning of the B Notebook, we can see three assumptions about nature which guided these early speculations, and which are essential to understanding the inventional work which Darwin performed with his tree diagrams later in the B Notebook: the *evolution* assumption, according to which species and higher taxa come into being by evolving from existing taxa; the *species aging* assumption, according to which species, like individual organisms, die when their finite life energy has run out; and the *distributed individual* assumption, according to which it is reasonable, especially for asexually reproducing organisms, to treat the many descendants of a particular organism as being the same individual as their parent, but dispersed through time and space.[31] The inventional work of the first half of the B Notebook, and especially of the tree diagrams employed there, primarily involves evaluating these three assumptions, finding ways to

[30] We do not have a textual record dating Darwin's turn to transmutationism, but it appears to have occurred sometime between early 1836 and early 1837, probably rather gradually (Richardson 1981; Herbert 2005, 316-320; Brinkman 2010).

[31] A fourth assumption was also important in the early pages of the B Notebook, but I have omitted it to simplify the analysis. This is the assumption that the number of species alive on earth at any given time remains approximately constant, with the birth of new species making up for the extinction of old species (B 20-21, 36-41). Darwin derived this assumption from thinkers as diverse as Cuvier, Lamarck, and Lyell, and held it to be true at least up through the summer of 1837 (Egerton 1968, 228-230; Kohn 1980, 99-100; Hodge and Radick 2003, 48; Herbert 1995).

represent them verbally and visually, and playing these assumptions against one another to clarify their value and relationships. To understand how Darwin employs visuals in the B Notebook, then, it is first necessary to understand these three assumptions and why Darwin found them plausible.

Darwin's first assumption was that the history of life on earth was an evolutionary history, with individual species giving rise to multiple descendant species by way of branching evolution. Darwin's first evolutionary speculations in the Red Notebook dealt primarily with individual species of organisms, or with pairs of species. For example, Darwin discusses how the macrauchenia, which he took to be an extinct llama, might relate to existing llamas, as well as the likely relationship between the two species of rhea which he found in South America (RN 127, 129-130, 153). In the B Notebook, the evolution assumption gains in complexity, and Darwin begins to discuss the evolutionary relationships between *multiple* species (and higher taxa) of organisms. Darwin accomplishes this more difficult task with the aid of kinship analogies. Referring to the relationships between several South American animals, for example, Darwin suggests that "We may look at Megatherium, armadillos & sloths as all *offsprings* of some still older type [,] some of the *branches* dying out" (B 20, emphasis added; see also B 40-41, B 54). Darwin also speaks of "branches" and "branching" in other B Notebook passages (e.g. 23, 28). In short, Darwin's acceptance of transmutation requires that he explore relationships among taxa of living things. But the move from discussing relationships between *pairs* of species in the Red Notebook to discussing the relationships between *multiple* species in the B Notebook also produces a new reasoning strategy: the use of kinship analogies and tree metaphors to clarify these relationships. These analogical reasoning strategies at the beginning of the B

Notebook help to pave the way for the family tree diagrams which Darwin employs shortly thereafter.

Darwin's assumption of evolution is one which we are used to associating with him. His next assumption about nature, however, seems in retrospect decidedly anti-Darwinian. This is the species aging assumption, the belief that each species has a determinate lifespan.[32] As Darwin puts the point in the Red Notebook, "Tempted to believe animals created for a definite time" (129). Just as an individual organism dies when its vital force has run out, so an entire species becomes extinct when its collective vital force runs out: "as with the individual, so with the species, the hour of life has run its course, and is spent" (Darwin 1839, 212). That Darwin should have such an outlook in the1830s may be surprising in light of his later work, but he was in good company. In classes he took with the botanist John Stevens Henslow, and in conversations with the paleontologist Richard Owen upon his return from the *Beagle*, Darwin picked up vitalistic ideas ultimately derived from Alphonse de Candolle and Fritz Müller (Sloan 1986, 376-378, 427-430).[33] Like these other thinkers, Darwin viewed vital force as a deterministic force governed by principles of energy conservation. This vital force could be used to increase an individual organism's complexity, or it could be used to extend an individual organism's life. Thus, very simple, asexually reproducing organisms could be potentially immortal, while organisms using a great deal of life force to create complexity would tend to be relatively short-lived. (Sloan 1986, 408-09, 426). The length of an organism's lifespan, then, would be inversely related to the complexity of its body.

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[32] In the Darwin scholarship, this idea is typically referred to as "species senescence." For thorough reviews of the origins of this idea and Darwin's application of it in his notebooks, see Kohn (1980) and Sloan (1986).

[33] Another, independent source for Darwin's idea of species aging may have been Giovanni Brocchi's idea of entire species going extinct all at once, an idea which Darwin would have encountered during the *Beagle* voyage while reading Lyell's *Principles of Geology* (Kohn 1980, 161-62n; Sloan 1986, 394).

But the vitalistic ideas of Henslow, Owens, Candolle, and Müller applied to *individual* organisms. Darwin's vitalism differed in a crucial way: it instead applied to whole species. Darwin's extension of vitalism from individual organisms to species may have originated in arguments among naturalists, especially botanists, about what should count as an individual organism. For example, when a strawberry plant is reproduced by cuttings, do the new strawberry plants count as new individuals, or are the new plants in some sense the *same* individual as the original plant? (Hodge 1985, 212). An important participant in such debates was John Stevens Henslow, Darwin's botany professor at Cambridge, who suggested that "the 'individual' in such forms is really an entity spread out in time as well as space, potentially immortal in duration" (Sloan 1986, 393; see also Sloan 1985, 99-103). Ideas like Henslow's provided Darwin with the first draft of his distributed individual assumption.

In the *Beagle* observations which Darwin was busily digesting for publication (1839), this assumption appeared to receive strong confirmation. On Chiloé Island, off the coast of Chile, for example, Darwin had seen apple trees which could be regrown from cuttings to an extent unprecedented in his experience: merely burying sticks from such a tree could result in the growth of a whole orchard (Darwin 1839, 363-64). Moreover, Darwin's microscopic investigations during the voyage convinced him of hitherto unobserved similarities between the asexual reproduction of microscopic plants like coralline algae, microscopic animals like coral polyps, and larger, multicellular organisms (Sloan 1985; Hodge 1985). In an 1835 note written during the voyage, Darwin began to speculate on these connections: "The following analogy I am aware is a false one; but when I consider the enormous extension of life of an <u>individual</u> plant, seen in the grafting of an Apple tree. & that all these thousand trees are subject to the duration of life which one bud contained[,] I cannot see much difficulty in believing a similar duration might be propagated with true generation [i.e., sexual reproduction]" (2v, reproduced in Herbert 1995). In short, Darwin came to believe that a distributed conception of biological individuality might apply, not just to phenomena of asexual reproduction like those found in strawberry plants and Chiloé apple trees, but also to sexually reproducing animals, as well.

By the time of the Red Notebook, this "false" analogy has gained Darwin's trust and become a guide to research, and Darwin has come to apply the distributed individual assumption even to sexually reproducing organisms. This is particularly obvious in his account of the mass extinction of large mammals in South America. In his account of the *Beagle* voyage, ultimately published in 1839, Darwin describes paleontological evidence for this mass extinction, an extinction which seemed to occur without any evidence of a major change in the environmental conditions of those mammals. Moreover, other species living at the same time—mollusks, for example—did not seem to be affected by this extinction. Darwin's explanation for this mass extinction is that, like the buds of a tree or the asexually produced offspring of a zoophyte, the members of a sexually reproducing species may be granted as a group only "a fixed and determined length of life:" "Among the greater number of animals, each individual appears nearly independent of its kind; yet all of one kind may be bound together by common laws, as well as a certain number of individual buds in the tree, or polypi in the Zoophyte" (212).

Similarly, Darwin speculates early in the B Notebook that the immense longevity of fish and reptiles in the fossil record, and the relatively short lifespans of mammalian species, might be explained in terms of a species-wide vital force. If a species' life force is used predominantly for added complexity, then there will be less vital force available for longevity. The "monad" from which a species originally arose would only have a limited vital force. Thus, "If we suppose monad definite existence [i.e., definite duration]. . ., then those [species] which have changed most owing to the accident of positions must in each state of existence have shortest life. Hence shortness of life of Mammalia" (B 22-23). Thus, not only can vitalistic ideas of species aging explain the apparently causeless extinction of large South American mammals, but it can also explain why mammalian species would tend to spend less time on the planet than simpler fish or reptile species.

Thus, two dozen pages into the B Notebook, Darwin has his work cut out for him. He has a voluminous mass of *Beagle* observations to work from, observations which he is simultaneously ordering and drafting elsewhere for publication. He has a strong sense that an evolutionary explanation is the correct one, and has even developed novel reasoning strategies—the use of genealogical analogies and tree metaphors—to aid him in crafting such an explanation. He has the species aging assumption, according to which the vital force of a species determines its life span, such that species die out for much the same reason that individuals die out, and not because of any environmental changes. And finally, he had the distributed individual assumption, according to which the descendants of organisms, especially asexually reproducing organisms, are frequently best thought of as being the same individual as their parent. Only after establishing these theoretical positions does Darwin begin to employ diagrams as an aid to ordering, clarifying, and elaborating upon his ideas and his observations.

The B Notebook Diagrams

Darwin's goal at the beginning of the B Notebook is simple: to combine his various observations and assumptions into a coherent transmutation theory which *includes* his assumptions and *explains* his observations. Darwin uses genealogical diagrams of species to pursue this goal. As we will see, Darwin used two primary sorts of moves in his visual-verbal invention. First, when considering a particular problem, he shifts from the verbal to the visual modality, using new insights generated by the diagram to add to his understanding of the problem. Second, while keeping his attention focused on a visual produced in order to think through one problem, he then shifts to using the same visual to examine a different problem. In short, Darwin alternates between two opposite strategies: switching modality while leaving subject matter constant, and switching subject matter while leaving modality constant. By shifting strategies in this way, Darwin is able to generate novel inferences about nature, that is, to produce potential theoretical innovations. Insights gained with the help of these diagrams allow Darwin to reject species aging, and help him to feel his way toward an account of how discrete, non-overlapping species and higher taxa can be produced by gradualistic evolutionary processes. Darwin's diagrams also allow him to develop novel reasoning strategies, new conceptual moves which seem useful in the development of theory. One such set of strategies is already in place before Darwin begins employing family tree diagrams: the use of kinship analogies and tree metaphors to shed light on the relationships among groups of living and extinct animals. With the aid of his diagrams, however, Darwin is also able to develop two additional reasoning strategies. First, he comes to approach puzzles about genealogical and taxonomic relationships between organisms by assuming an extinct common ancestor; and second, when he finds a fact or rule which applies at the level of species, he examines whether this same fact or rule may be applied at a higher level of taxonomic generality.

But in addition to helping him to develop novel inferences about nature and novel reasoning strategies, Darwin's diagrams also provide a third service. In drawing a series of genealogical diagrams, Darwin develops novel representational practices that govern future diagrams. Darwin's changing representations of extinct groups of organisms in these diagrams, for example, interact in complex ways with his existing knowledge and with the novel inferences and reasoning strategies which he is also developing. Similarly, the progressively more detailed branchings in Darwin's family trees are informed by and subsequently inform Darwin's stock of inferences and reasoning strategies. Thus, the diagrams in the B Notebook not only steer Darwin toward novel inferences that may be elaborated upon to produce theoretical innovation; they also generate ways of reasoning about and representing nature that are valuable in future iterations of inventional work.

By the twentieth page of the B Notebook, Darwin has already begun discussing evolutionary relationships between living and extinct groups of organisms in terms of familial relationship and "branches." Darwin continues this reasoning, wondering about the overall structure of the tree of life at its most general level: "Would there not be a triple branching in the tree of life owing to three elements air, land & water, & the endeavour of each typical class to extend his domain into the other domains [?]" (B 23). This idea presents a problem, however. Should we not expect to find intermediate forms comprising a smooth gradation between different "branchings?" As Darwin puts this concern, "We need not think that fish & penguins really pass into each other" (B 25). Analogizing from the corals which he spent so much time studying on the *Beagle*, Darwin suggests that this concern could be put to rest by assuming, not a smooth gradation of forms connecting, e.g., fish and penguins in a straight line, but rather an ancestor from which both fish and penguins have arisen: "The tree of life should perhaps be called the coral of life, base of branches dead; so that passages cannot be seen" (B 25). The apparent similarities in traits between organisms show their relatedness, but the true character of that relatedness is invisible because of the extinction of common ancestors. Darwin is thus trying out a new reasoning strategy, which could be represented as follows: When presented with a puzzling taxonomic or evolutionary phenomenon, try to explain it in terms of existing groups of organisms arising from a shared, now-extinct ancestor.

Darwin is now juggling several ideas at once: a triple-branching tree of life, common ancestry as an explanation for trait similarity in organisms from different "branchings," and extinction eliminating information about this common ancestry. He makes the job easier for himself gathering together these various knowledges into a single cross-modal perspectivization—in short, he constructs his first genealogical diagram (see Figure 3.1). The vertical axis represents time, while the horizontal axis represents trait difference. Straight lines represent observable relationships between organisms, while dotted lines represent unobservable organisms, like the posited common ancestor of fish and penguins.

Figure 3.3: Darwin's first B Notebook tree diagram (26).

Having sketched this diagram, Darwin immediately begins to employ its representational resources to investigate further how existing taxonomic relationships between organisms could have resulted from past evolutionary relationships. He asks "Is it thus fish can be traced right down to simple organization. — birds — not?" (B 26), and draws a second diagram (see Figure 3.2). The second diagram uses the same visual conventions as the first, but zooms in on two particular branches of the tree of life. Each of these two branches is also given more detail. For the first time in his evolutionary theorizing, each branching of the tree of life has come to have branchings of its own. Such branching occurs sometimes in ordinary genealogical diagrams, of course, but the direction of the nested branching is reversed: each person represented in such a diagram has two parents, four grandparents, and so on. Since the elements of Darwin's genealogical diagrams are species which branch and not individuals produced by pairs of parents, the nested branchings are an extension of Darwin's original diagram which are not directly borrowed from existing family tree diagrams. The new representational practice which Darwin inaugurates with his second diagram—the explicit presentation of nested branchings—will be a staple of Darwin's visual representations of nature all the way through the final presentation of his evolution theory in 1859. It will also help Darwin to develop novel inferences and reasoning strategies of great importance to his investigation.[34]

Figure 3.4: Darwin's second B Notebook tree diagram (26).

[34] Just as Darwin tries out a number of reasoning strategies in his notebooks, only some of which come to be reliable special topoi, he also tries out a number of representational practices, only some of which come to be visual conventions carried through in later iterations of inventional work.

But Darwin's second diagram doesn't just introduce a new representational practice: it also allows him to think in a new way about the classification of living things. In the 1820s and 1830s, there were several approaches to such classification. The most influential for Darwin, and for many other naturalists during this time, was the so-called quinarian system of William Sharp MacLeay (1819; Ospovat 1981). MacLeay treated animal classification in terms of nested circles of taxa. At the top of this scheme are the five classes: mollusks, vertebrates, arthropods, radiates, and simple, microscopic animals called acrita. Each of these classes is a circle comprised of five orders; each of these orders is a circle comprised of five tribes, and so on, as show in Figure 3.3. On the basis of his second diagram, however, Darwin begins to suspect that the appearance of "circles" in animal taxonomy is not a real feature of an orderly Creation, but rather an artifact of the extinction of shared ancestral forms. As "the bottoms of branches deaden," Darwin writes, "in Mammalia, birds, it would only *appear* like circles" (B 27; emphasis added). The circular taxa of quinarianism, then, happen because some common ancestor has disappeared, and not because taxa really are arranged in nested circles.[35] Just as Darwin's first diagram allowed him to connect fish to penguins by positing an extinct ancestral form, his second diagram shows him that apparently synchronic and circular taxa are actually more like diachronic cones whose point of origin has been eliminated by extinction. In both cases, Darwin applies the same reasoning strategy: when faced with a taxonomic puzzle or question, see whether a now-extinct common ancestor may be used to resolve the difficulty.

[35] Though Darwin thus makes quinarian ideas of taxonomy unnecessary with the inferences aided by his second diagram, he continued to believe that something like a quinarian view might be a plausible approach to classifying living things. Indeed, Darwin's own idea of a triple-branching tree of life, mentioned earlier and revisited later in the B Notebook, is a sort of simplified quinarianism (B 263; Voss 2010, 90). By the end of 1837, however, Darwin seems to have utterly rejected any quinarian system in favor of the idea that taxa are the result of common descent (C 170; see also D 50-53).

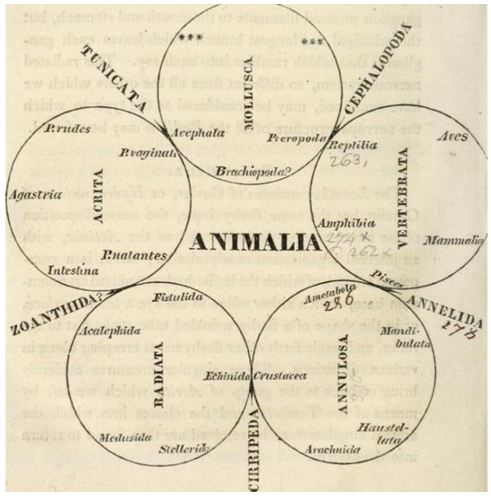


Figure 3.5: MacLeay's (1819) quinarian scheme (318).

The nested branching of the second diagram, and its ability to give an alternative account of quinarian circular taxa, also leads Darwin to an important theoretical innovation: the refutation of species aging. Immediately after his second diagram and its nested branchings, Darwin briefly describes two real-world examples of taxonomic nesting: "Petrels have divided themselves into many species, so have the Awks [sic]" (B 28). Having moved from the order of birds to petrels and auks in particular to the species comprising the petrels and auks, Darwin is now attentive to the nested branching of his second tree diagram, and realizes that if nested, branching evolution actually happens, then species aging cannot. This is because if each species has a determinate amount of vital force, and if a given species can, through branching evolution, give rise to several daughter species, then each of these daughter species should have the same amount of vital force, derived from their shared ancestor. But if this is true, then entire genera should go extinct relatively frequently, since the species comprising such a genus would all have the same amount of vital force. Indeed, this logic could be taken further: if the various genera within a class all arose from a distant shared ancestor, then the species aging assumption should lead us to expect even entire classes to go extinct relatively frequently: "As all the species of some genera have died, have they all one determinate life dependent on genus, that genus upon another, whole class would die out, therefore not" (B 29e).[36] Since the frequent extinction of entire classes of organisms is not observed, Darwin says "Monad has not definite existence"—that is, the original germ starting off a given species cannot have a determinate lifespan (B 29e).[37] It is important here to note the relationship between the branching evolution depicted in Darwin's second diagram and the logic of his refutation of species aging. Darwin begins with an assertion about the relationship between a set of daughter taxa and the genus which they comprise: "As all the species of some genera have died, have they all one determinate life dependent on genus." He then moves this assertion to a higher taxonomic level, shifting to the relationship between a set of genera and the class which *they* comprise: "that genus [dependent] upon another, whole class would die out, therefore not." Given the nested branchings which Darwin assumes, he here tries out a novel reasoning strategy: When you find an assertion which is true at one taxonomic level, try shifting it to a higher taxonomic level and see what results. It is not possible to show with certainty how exactly this verbal argument, Darwin's second tree diagram, and the reasoning strategy of shifting an inference from the species-and-genus level to the genus-and-class level relate to one another: it is clear, however, that all three arise at very close to the same time in a

[36] There were other ways for Darwin to get around this problem, of course. For example, he could try to find some way to assert that the daughter species arising from a common ancestor might, for various reasons, use up their vital force at different rates, or that for whatever reason, vital force need not be equally shared among daughter species. Darwin does not, however, examine these possibilities either in the B Notebook or elsewhere.

[37] My analysis of Darwin's reasoning in this and the following paragraph are indebted to Sloan (1985, 442-43).

way that connects verbal, visual, and conceptual aspects of this notebook passage, and which allows Darwin to reject species aging.[38]

Having apparently refuted the doctrine of species aging to his own satisfaction, Darwin is still left with the puzzle of how the large mammals of South America went extinct all at once, apparently "*independent of external causes*" (B 35). Darwin answers this question with a striking sentence: "I think," followed by the diagram reproduced in Figure 3.4 (B 36). This diagram zooms in even further than the second: a single ancestral form, marked "1," has given rise to 13 currently existing species divided into four genera, marked A, B, C, and D. As before, time is mapped vertically and trait difference horizontally, but Darwin here tries out a representational practice which is new for him: rather than representing only the now-extinct common ancestors of currently extant organisms, as in his first two diagrams, Darwin here also represents species which went extinct without leaving any descendants.[39] This new representational practice, which will become a permanent part of Darwin's repertoire, is immediately followed in the text by a novel inference: the extinction of certain species yields gaps between groups of forms, such that "between A & B immense gap of relation. C & B the finest gradation, B & D rather greater distinction. Thus genera would be formed" (B 36). Thus, discrete taxa of organisms are the result, not just of shared ancestry, but of extinctions producing gaps between related clusters of species. It cannot be shown with certainty whether Darwin is reading this inference about extinction and discrete taxa from his diagram, whether he had the inference first and sketched the diagram to test it, or whether both arose from some third source: nevertheless, it is clear that

[38] Shortly after this, Darwin provides a second, similar refutation of the species aging assumption which is based on biogeographical evidence (B 35). For a discussion of the biogeographical observations involved, see Sulloway (1982).

[39] Naturally, this representational practice also appears in ordinary family tree diagrams whenever a person represented in the diagram leaves no offspring. But given the purposes of his first two diagrams, the analogous case of the *species* which leaves no offspring has not yet arisen in Darwin's sketching.

Darwin's representational practices (depicting extinct forms which left no descendants) and his novel inferences about nature (extinctions produce gaps between taxa) inform, constrain, and reinforce one another as he writes and sketches.

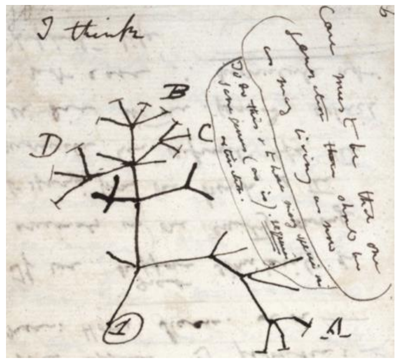


Figure 3.6: Darwin's third B Notebook tree diagram (36).

At this point, Darwin has found two reasoning strategies that have provided him with useful results: approaching taxonomic and evolutionary puzzles in terms of common descent from a single, now-extinct ancestor; and the movement of a given inference to a higher taxonomic level. Darwin has also begun to employ a new representational practice: rather than only representing now-extinct forms which gave rise to now-existing descendants, Darwin represents even extinct organisms which left no descendants whatsoever. Darwin combines these elements with his results so far to solve a new problem: why pairs of larger taxa, such as plants and animals, should seem so utterly distinct from one another. If even pairs of higher taxa like plants and animals, vertebrates and arthropods, or mammals and birds all evolved gradually from a common ancestor, why should there be such an immense difference in traits between them, with no intermediate forms?

Darwin begins with a reasoning strategy that has already shown promise: he takes an inference applicable at one taxonomic level and shifts it to a higher taxonomic level. He moves back from the form marked 1 in his third diagram (Figure 3.4) to an even more remote common ancestor: “the source of the Mammalian type of organization” (B 40). Darwin realizes that this form was, at one time, a single species. It has since blossomed into many thousands of species. In the third diagram, a single species-extinction is enough to produce a noticeable gap between two genera, that is, between two groups of species. But as time and branching evolution continue, the offspring-species of the two genera come to be families or classes, and the gap left by a single species’ extinction becomes larger, as well: thus, “[the] *greater the groups the greater the gaps*. . . between them. — for instance, there would be great gap between birds and mammalia, Still greater between Vertebrate and Articulata, still greater between animals & Plants” (B 42-43). Thus, the more branching evolution that has taken place in two discrete taxa, the larger the two *taxa* will each be, as shown by the progression from birds/mammals to vertebrates/articulates to animals/plants; likewise, the more time has passed since the extinctions that rendered the taxa discrete, the larger the *gap in traits* between the two taxa will be. Thus, not only does extinction allow for discrete taxa even within a gradualistic evolutionary context; it is also the case that the extinction-caused gaps between taxa grow over time. Two obvious facts about the relationships among organisms—that taxa are distinct and that gaps between large taxa are more pronounced than gaps between small taxa—are thus straightforwardly explicable in evolutionary terms.

Though we lack direct access to Darwin's brain, or even to a think-aloud protocol of his inventional work, it is clear that Darwin develops novel representation practices, novel inferences about nature, and novel reasoning strategies concurrently in the construction of his theory, and that these three elements inform and constrain one another as Darwin is writing and sketching. Darwin's process of theory construction involves recurrent shifting among visual and verbal modalities, with this shifting allowing for the same problem to be looked at in a new way. Thus, having drawn a first diagram in which three existing taxa share an extinct common ancestor, Darwin asks himself whether such a common ancestor might explain why "fish can be traced right down to simple [i.e. primitive] organization," while birds cannot (B 26). Darwin explores this question with a second diagram, which yields further rounds of invention.

Less obviously, Darwin's visual-verbal invention also sometimes involves staying with the same sketch, but looking at it from a new perspective. Thus, Darwin's second diagram begins as a tool for representing his question about fish and birds, but is then shifted to become a new way of looking at the classification of living things: if "the bottoms of branches deaden," Darwin realizes, it would give the appearance of circular taxa employed in quinarian classification systems (B 27). Darwin thus uses multimodality in two ways in the course of the B Notebook: first, he shifts examination of a particular issue from one modality to another; second, he maintains attention to a particular sketch, but switches from one investigative purpose for that sketch to a different one. Darwin will adapt these two forms of shifting in the 1859 presentation of his theory.

These shifts in modality and perspective produce novel insight about nature—indeed, this seems to be their primary purpose. But they also require Darwin to move from concepts in his mind to sketches on paper, a move which forces specificity in how Darwin represents nature. For example, the idea of "extinct common ancestor" or "branching tree of species" is underdetermined. In the act of sketching representations of these concepts, Darwin must decide what sorts of elements to represent, and in what detail. He must decide what sorts of lines and shapes to use for different diagram elements. And as Darwin moves from his first to his second to his third sketched diagram, we see these decisions changing. Elements not present in the first diagram—nested branchings, species which went extinct without leaving a common ancestor—come to be quite noticeable by the third diagram. During his visual-verbal invention, then, the increased specificity needed to draw a diagram forces Darwin to inaugurate novel representational practices which inform subsequent rounds of visual-verbal invention.

But in addition to theoretical and visual innovations, Darwin's inventional process also produces innovative reasoning strategies. In particular, Darwin tries out two such strategies—seeing whether an extinct common ancestor of two existing taxa would explain their current features and relationship, and shifting an inference to a higher taxonomic level—and finds that they yield interesting and valuable insights. The common-ancestor strategy suggests a way to get around the question of whether a line of intermediate forms must connect, e.g., fish and penguins, and also suggests an explanation for why the circular taxa of quinarianism might seem plausible without being real. Similarly, the taxon-shifting strategy allows Darwin to reject the assumption that species have a determinate lifespan, and also helps him toward the idea that larger taxa will have greater gaps in traits between them. By shifting modalities, then, Darwin simultaneously generates theoretical, representational, and cognitive innovation. His assertions about nature, his means of visually representing nature, and his strategies for developing new inferences about nature all arise simultaneously as he writes and sketches in his notebook.

Tree Diagrams in the Post-Notebook Period

Between 1837 and the late 1840s, we have no further record of Darwin using genealogical diagrams in his inventional practice. In the late 1840s and 1850s, however, Darwin again begins to experiment with the form, first to investigate how marsupials and other mammals arose from their common ancestor, then in a never-completed, book-length draft of his evolution theory tentatively titled *Natural Selection* (Brink-Roby 2009; Voss 2010; Archibald 2012; Pietsch 2012). These post-notebook-period diagrams do many of the same things as the B Notebook diagrams, such as depicting evolutionary change, extinction, and the relationships among taxa of organisms. Since the B Notebook, Darwin's understanding of these entities and processes has stabilized; Darwin is no longer engaging in theoretical speculation during this time. He is, however, still experimenting with visual representation practices, ways to represent his now largely stable theory persuasively. Between the B Notebook and the *Origin* in 1859, Darwin adds to the complexity of his tree diagrams, adds more regimentation to their time dimension, and even imports visual conventions from geometry.

But there is more. Darwin is also experimenting with his novel genre—the evolutionary tree diagram—with the goal of developing an overarching visual-verbal rhetorical strategy. This strategy, first developed in *Natural Selection* between 1854 and 1858, involves using the same tree diagram first for one representational purpose, then for another. After first using the diagram to represent core concepts in his theory, Darwin then uses it to represent how the formation of new species is explained by his theory, then how the formation of larger taxa is explained by his theory. Finally, Darwin uses the diagram to show how existing observations about paleontology and the taxonomic relationships among organisms could be explained by his theory. By shifting the representational role of a single visual in this way, Darwin is able to suggest to readers that his theory, simple as it is, has the explanatory power to tie together a great diversity of facts about nature. Moreover, as we will see, Darwin's novel representational strategies are developed throughout the 1850s with an eye to this comprehensive, visual-verbal rhetorical strategy. As Darwin moves from *Natural Selection* to the *Origin*, his representational conventions and his rhetorical strategy continue to evolve together, informing and constraining one another. Just as Darwin's visual-verbal invention in the B Notebook helped him to simultaneously develop inferences about nature, representational practices, and reasoning strategies, so his visual-verbal invention in the 1850s allows him to simultaneously develop rhetorically compelling representational practices and a visual-verbal rhetorical strategy which will make the best use of those practices. In short, Darwin's early development of a compelling body of knowledge claims, representational practices, and reasoning strategies gives way in the 1850s to the development of an overarching visual-verbal rhetorical strategy which is grounded in an intensively revised tree diagram.

In the late 1840s or early 1850s, Darwin became interested in the evolution of marsupials and placental mammals from a single common ancestor, and used tree diagrams to think about this process (Archibald 2012). Figure 3.5 shows one such diagram. Written sideways at the base of the tree is the diagram's subject: "Parent of Marsupials & Placentals."[40] The three major branchings of the tree, then, from bottom to top, are the marsupials, the rodents, and some other (unidentified) family of placental mammals. Between the latter two branches is a circled cluster of extinct forms. To the left of this cluster, Darwin writes "If these had all given descendants then this [would] have been a great series;" to the right, Darwin writes "no forms intermediate." We thus see several similarities between this tree diagram and those from the B Notebooks: taxa

[40] I here rely on the transcriptions of diagram text provided in Archibald (2012, 218-19).

are identified by common descent, branchings of the tree of life (taxa) each have sub-branchings of their own (sub-taxa), and the definite boundaries between taxa are the result of the extinction of intermediate forms.

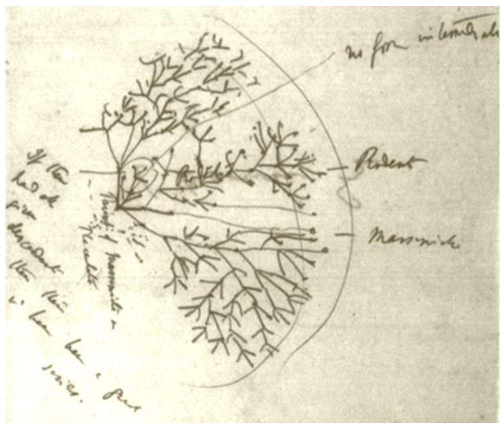


Figure 3.7: Darwin's diagram depicting the common ancestry of marsupial and placental mammals (reproduced from CUL-DAR 205.5.183r)

But there are three important innovations in this version of the tree diagram. First, unlike the B Notebook diagrams, this diagram involves several layers of nested branching, not just one, two, or three. So "bushy" are these branches that Darwin feels obliged to arrange the diagram radially, as part of a circle, rather than as a simple line with branches radiating from it.[41] Second, Darwin has stopped using numbers and letters to refer to taxa: instead, he attempts to apply the logic of his prior tree diagrams to an existing taxonomic relationship between real groups of

[41] Several naturalists at around this time attempted to represent their (non-evolutionary) scheme of the natural system using such a radial arrangement; see Pietsch (2012), Figures 31 and 32. A likely source for Darwin's radial approach here was the 1848 frontispiece to Louis Agassiz's *Principles of Zoology* (Brink-Roby 2009, 256-58; Voss 106-08; Pietsche 2012, 86).

organisms, perhaps as a way to test certain of his B Notebook speculations. Third, Darwin attempts to add some regimentation to the time dimension. Unlike the B Notebook tree diagrams, there are two curved, concentric lines toward the ends of the branches, apparently intended to represent two distinct time-periods. This representational practice is underdeveloped—Darwin does not seem to be making any particular point with it—but in later diagrams, this regimentation of the time dimension will begin to do a great deal of representational heavy lifting for Darwin.[42]

Darwin seems to be using this radial diagram in part to investigate a phenomenon which has interested him since the B Notebook: why is it that many genera have species which seem to belong in "adjacent" genera? For example, petrels spend a lot of time either in the air or floating on the surface of the water. In Tierra del Fuego, however, Darwin found a species of petrel which flies very seldom, instead spending most of its time diving and swimming underwater, exactly as though it were an auk (Darwin 1859, 184-85). Referring specifically to such auk-like petrels, Darwin asks in the B Notebook why it is "that there come aberrant species in each genus. . . approaching another" (28). His provisional answer is that such aberrant species might be "an index of the point whence, two favourable points of organization commenced branching" (28; see also 121). Thus, the petrels and the auks share a relatively recent common ancestor, and the diving petrel is simply the species in one of these branches that is closest to the other branch.

Darwin's radial diagram represents this explanation of aberrant taxa with reference, not to petrels and auks, but to wombats and bizcachas. The bizcacha or viscacha (*Octomys mimax*) was believed at this time to be a rodent closely related to marsupials, largely on the basis of

[42] For my purposes, it is only the visual innovations of this diagram which are important. For a fuller account of Darwin's purpose in diagramming the common ancestry of marsupial and placental mammals, see Archibald (2012).

certain features of its reproductive system; the wombat, meanwhile, was believed to be a marsupial closely related to rodents, largely on the basis of peculiarities of dentition (Archibald 2012, 226-27). Darwin wrote about the apparent similarity of bizcachas and marsupials, and of wombats and rodents, in both his 1844 *Essay* and in the 1859 *Origin* (1844, 203-04; 1859, 429-430). In Darwin's radial diagram, these two organisms appear between the main branchings labeled "Rodent" and "Marsupials." They are the two long, straight twigs of this tree where these two branchings most closely approach one another. Darwin is thus able to visually render a plausible explanation for the odd relationship between a rodent-like marsupial and a marsupial-like rodent, and to do it in terms of the theory which he is developing.

The problem, however, is that naturalists of the time were divided on just how rodent-like the wombat's teeth were. Referring to the wombat by its scientific name, *Phascolomys*, Darwin mentions in his 1844 *Essay* the difficulty of "determining what are analogical or adaptive and what real affinities; it seems that the teeth of the Phascolomys though *appearing closely* to resemble those of a Rodent are found to be built on the Marsupial type; and it is thought that these teeth. . . may have been adapted to the peculiar life of this animal and therefore may not show any real relation" (203). Since Darwin cannot be certain whether the rodent-like teeth of the wombat result from shared ancestry with rodents or from a fortuitous similarity caused by similar habitat and way of life, he also cannot use the bizcacha as a clear-cut example when publishing his theory. Indeed, any such specific group of organisms used as an example for such a diagram would have to be a clear-cut case of common descent, such that further knowledge about the organisms in question would not cast doubt on the diagram, and by extension on the theory itself. After the radial diagram showing the bizcacha and the wombat, then, all of

Darwin's future diagrams avoid depicting evolutionary processes which involve particular, real taxa of organisms.

But the inventional value of Darwin's radial diagram is not purely negative. Two of Darwin's innovations in visual representation—more nested branching and a more regimented time dimension—are continued in future rounds of visual-verbal invention. The next step in this visual-verbal invention which still survives is found in Darwin's never-completed, book-length presentation of his theory, tentatively titled *Natural Selection* and begun in 1854. As might be expected, the portion of this book which Darwin completed has an arrangement similar to his finished theory-presentation, *On the Origin of Species*. The first three chapters of *Natural Selection* argue that new breeds of plants and animals are created by a process which Darwin calls *artificial selection*. Chapters 4, 5, and 6 define Darwin's concept of *natural* selection and present it as the cause of taxon formation in nature. Darwin notes in chapter 6 that both artificial and natural selection require competition between organisms resulting in extinction, "one species whilst forming beating out another. . . . It is in each country, a race for life & death; & to win implies that others lose" (227). Darwin also describes the relationship between natural selection and the divergence of traits. When descendants of a single species have traits different from one another, and different from their shared ancestor's, "a far greater number of individuals descended from the same parents can be supported," since their varying traits allow them to occupy very different niches "in the polity of nature" (228). Darwin thus presents extinction, trait divergence, and natural selection as integrally related to one another, and as all operative in the creation of new taxa. After illustrating these three principles with several imaginary cases, Darwin has in his first six chapters laid the groundwork for his tree diagram—the first tree diagram he has constructed specifically to present theory to an audience other than himself (see Figure 3.6).[43]

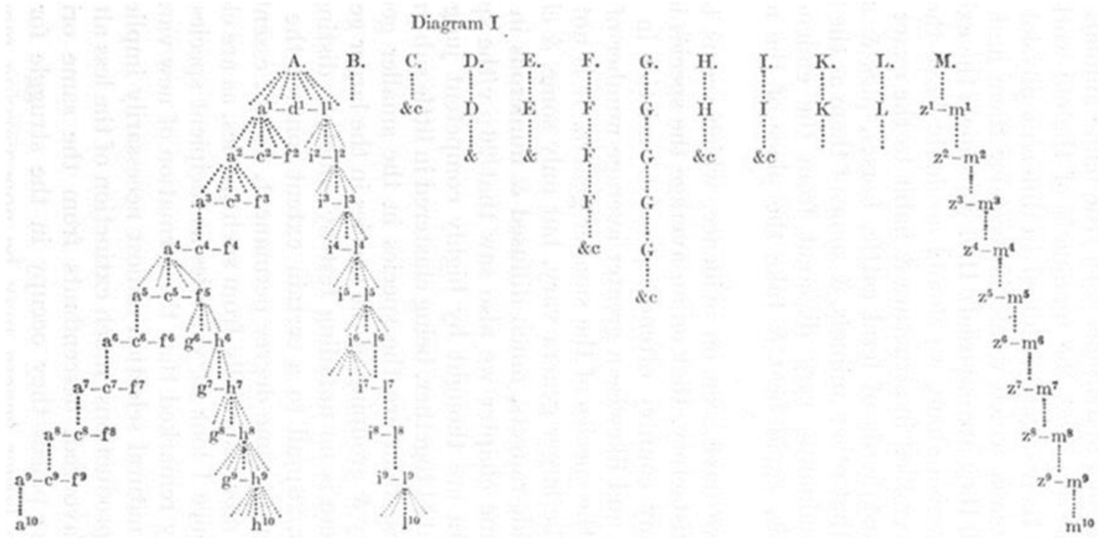
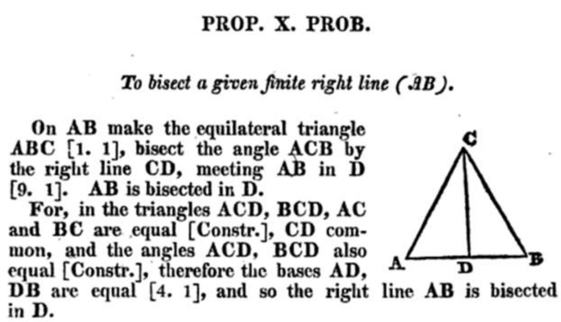


Figure 3.8: Darwin's first tree diagram from *Natural Selection* (1975, 236-37).

For this diagram, Darwin borrowed visual conventions from plane geometry to help him depict complex natural phenomena (Brink-Roby (2009) 248). Darwin studied geometry with a private tutor as a boy, and the "clear geometrical proofs" gave him "intense satisfaction" (Darwin 1958, 43). He continued studying geometry at Cambridge (59). We do not know exactly which editions of Euclid's *Elements of Geometry* Darwin used at these times, but since they all share many well-entrenched visual conventions, this is fortunately not a barrier. In a typical

[43] Darwin actually presents two tree diagrams in *Natural Selection*, only the first of which I discuss here. Darwin's second tree diagram depicts the same taxa as the first, and in basically the same relationships, but assumes that the survival of offspring from one generation to the next is entirely random, rather than being the result of natural selection and divergence. The point of this second diagram, then, is to show that without natural selection and divergence, observed biodiversity cannot be adequately explained (1975, 243-44).

diagram from Allen's 1822 edition, for example, we see these conventions in action (Figure 3.7). A group of shapes and/or lines is presented, with each vertex or intersection marked with a letter. These letters allow for discrete reference in the accompanying text to particular diagram elements, like "line CD," "the equilateral triangle ABC," and "angle ACB." These pictorial elements can not only be referred to in the text, they can also be related to one another (verbally), and to concepts developed previously in the book (with the aid of references in brackets). These references to and elaborations upon pictorial elements then allow for complex inferences to be built up. In this particular case, the point of the diagram and its accompanying text is that when the angle ACB is bisected by CD, the side opposite the angle "is bisected in D." Moreover, the diagram and accompanying text not only tell us about *this* particular triangle and bisecting line, but about *any* such figure, regardless of its size.


PROP. X. PROB.

To bisect a given finite right line (AB).

On AB make the equilateral triangle **ABC** [1. 1], bisect the angle **ACB** by the right line **CD**, meeting **AB** in **D** [9. 1]. **AB** is bisected in **D.**

For, in the triangles **ACD, BCD, AC** and **BC** are equal [Constr.], **CD** common, and the angles **ACD, BCD** also equal [Constr.], therefore the bases **AD, DB** are equal [4. 1], and so the right line **AB** is bisected in **D.**

Figure 3.9: A typical geometrical diagram, reproduced from Allen 1822 (25)

Darwin adapts these geometrical visual conventions in the construction of the two family tree diagrams employed in *Natural Selection*, the first of which is reproduced as Figure 3.6. These diagrams show far more regimentation of the time dimension than any of Darwin's previous diagrams. As with a geometrical diagram, straight lines are the order of the day, and each taxon in the diagram gets its own label. This makes reference to particular points in the diagram easier. Darwin has also forsaken a radial arrangement (presumably to avoid having to deal with questions about the origin of all living things) in favor of a rectangular one. This representational practice also means that the "frame" of this diagram can slide up and down through the time dimension; thus, the starting point of this diagram could instead be the ending point, showing the common ancestry of forms A through M—a feature which will become more evident in Darwin's 1859 iteration of this diagram (Voss 2010, 117-18). By shifting from a radial to a rectangular arrangement, and by importing visual conventions from geometry, then, Darwin is able in this new iteration of the family tree to facilitate reference to particular points in the diagram as required by his argument, and to make arguments which extend above the top and below the bottom of the diagram by using accompanying language to shift the frame of the diagram up or down.

In introducing this diagram, Darwin reiterates the three core principles that have guided his presentation in *Natural Selection* up to this point: evolution by way of natural selection, divergence, and extinction. Darwin writes, "The complex action of these several principles, namely, natural selection, divergence & extinction, may be best, yet very imperfectly, illustrated by the following Diagram" (238). In the diagram, these three core principles of Darwin's theory are presented using conventions that have remained more or less stable since the B Notebook. The principle of divergence is depicted by the sprays of dotted lines emerging from many of the nodes. The principle of extinction is depicted by lines which stop at a certain point in time, like K and L. Finally, the principle of evolution through natural selection is depicted by lines connecting two nodes which are not perfectly vertical. Thus, the descendants of F and G do not differ noticeably from their ancestors, so their lines have no horizontal component. In a creationist map of what Darwin is representing, *all* taxa would be depicted by straight vertical lines like those of F and G. But with evolution, a10, h10, and l10, all descendants of A, are very different from one another and from their shared ancestor, as shown by their horizontal distance from one another. Darwin thus gives a visual presentation of these three key aspects of his evolution theory to complement the verbal presentation he has already given in preceding chapters. Insofar as a reader provisionally accepts Darwin's account of natural selection, trait divergence, and extinction, the diagram presents a plausible portrayal of what happens to groups of organisms over time. Moreover, insofar as this visual portrayal of evolutionary processes is accepted, Darwin can use it to develop further inferences for the reader about the results of such processes, compare these novel inferences to observed facts about nature, and so on

In the B Notebook, Darwin's diagrams involved abstract, notional taxa. The radial diagram, by contrast, was more concrete, involving the shared ancestor of rodents and marsupials, as well as two animals which seemed to have emerged very soon after this evolutionary branching. In *Natural Selection*, Darwin uses his diagram to guide readers through a thought experiment somewhat between these two extremes: the original taxa at the top of the diagram are species in a large and widespread genus of plants, with A and M being the most unlike one another—say, "A is the most moisture loving and M the least moisture-loving species" (239). The divergence of these species through time, Darwin writes, would continue "till they would be universally be [sic] ranked as good species; & the number of such new forms would continually tend to increase" (243). The last state represented in the diagram thus shows that as a result of evolution, "the genus will have become not only more divergent in character (a^{10} more aquatic than A; & m^{10} more drought-enduring than M.) but numerically larger," that is, containing more species (244-45). We here see two aspects of Darwin's visual-verbal strategy in *Natural Selection*. First, Darwin has attempted to mediate between the complete abstraction of his B Notebook diagrams and the risky specificity of the radial diagram, settling on a level of abstraction which allows him to describe specific traits—e.g., need of moisture—without tying himself to future changes in knowledge about particular organisms. Second, Darwin has attempted to produce a diagram which does two distinct representational jobs simultaneously: first, the diagram represents his three core concepts of extinction, divergence of traits, and evolution by way of natural selection: and second, it represents the thought experiment of the more-or-less aquatic plant species in a genus. Insofar as the verbal and visual aspects of these two jobs are able to work together harmoniously, Darwin has a diagram which first depicts his theory, then a concrete and plausible species-history derived from that theory.

In the B Notebook, Darwin used two sorts of shift in visual-verbal invention: the shift from one modality to another while maintaining a consistent subject, and the shift from one subject to another while maintaining a consistent modality. During the course of *Natural Selection*, Darwin moves his reader through these same sorts of shift while presenting his evolution theory. We have already seen an example of the first shift when Darwin moves from a verbal discussion of evolution, trait divergence, and extinction to the diagram. We have also seen an example of the second, when Darwin moves from using the diagram as a depiction of the three core concepts of his theory to using the diagram as a depiction of species formation in a taxon of plants. Staying with the same diagram, Darwin employs a subject-matter shift again to discuss the creation of higher taxa. Darwin invites the reader to suppose "the process illustrated in diagram I. to have long continued & the modified descendants of A to have become extremely much multiplied and diversified in many ways," such that "they will tend to take the places of &

thus exterminate the species B.C.D. &c" (245). In the same way, Darwin invites the reader to imagine that species M, on the far right side of the diagram, to have left many descendant-species which supplant species, L, K, and so on (245). Further, Darwin writes, suppose that all the species A through M originally arose from a single ancestor, called Z. The conclusion is that with all the intervening forms B through L having become extinct, common ancestor Z "will have become the ancestor of two or three very distinct groups of new species; & such groups, naturalists call genera" (246). Nor does Darwin stop here: "By continuing the same process. . ., Z may become the ancestor of two very distinct groups of genera; & such groups of genera, naturalists call Families or even Orders." (246). Darwin is thus able to take his tree diagram and extend its range, by verbal means, so that it represents the creation of higher taxa. By inviting the reader to extend the logic of the diagram to the common ancestor of forms A through M above the top, and by inviting the reader to extend the logic of the diagram below the bottom of the page, a family tree which already represents the core concepts of Darwin's theory and the generation of new species now also represents the generation of new genera, families, and orders.

Darwin then shifts subject-matters again so that his diagram can represent the fact, widely remarked by paleontologists of the time, that extinct organisms tend to have traits intermediate between those of living species. Describing this phenomenon in terms of his theory, Darwin writes that such an intermediate extinct form "may be fairly viewed on my theory as one of the intermediate links; the extinct form may have been the actual ancestor of our two species, or more probably it may be an early & less modified descendant of the common ancestor, either in the direct line of descent of one of the two species or in a collateral & extinct line" (264). To make this point more intuitively obvious to the reader, Darwin refers in a footnote to his diagram, using the labels of that diagram to ensure that the argument is easily understood and perceptually compelling: “Let a^{10} & l^{10} be two now living forms with all their ancestors extinct. If A should chance to be discovered it will be strictly intermedial, though it might in many of its characters far more resemble a^{10} than l^{10}” (264n.). Having presented his diagram as an account of taxon formation both large and small, Darwin now employs the same diagram to provide a novel account of a widely observed fact about paleontology.

In *Natural Selection*, then, Darwin has developed a comprehensive visual-verbal rhetorical strategy for presenting his theory. First, Darwin introduces his reader to the concept of evolution by way of natural selection, and argues that, like artificial selection, it has the power to generate new sorts of organisms in conjunction with divergence of character and extinction. Second, Darwin presents the tree diagram, positioning it as a visual representation of the three core concepts (evolutionary change, divergence, and extinction) already presented verbally earlier in the book. Third, keeping the reader’s attention on the diagram, Darwin shifts its function so that it successively represents the formation of new species, the formation of higher taxa, and the reason why extinct forms tend to have traits intermediate between those of existing forms. In this way, Darwin is able to suggest that his theory’s core concepts and the account of taxon formation which they imply can effectively explain a widely observed and puzzling fact about paleontology.

The Tree Diagram in the *Origin*

Darwin was not able to complete *Natural Selection* because as he was writing it, he received a letter from Alfred Russell Wallace showing that he had developed an evolution theory very similar to Darwin's own independently. Darwin left *Natural Selection* and began hurriedly preparing a more condensed presentation of his theory—*On the Origin of Species*. This book contains only one diagram, reproduced in Figure 3.8. Its conventions are similar to those in the *Natural Selection* diagram, but two key innovations show the impact of the visual-verbal rhetorical strategy first developed in *Natural Selection*. First, Darwin has turned the diagram upside-down, such that the original taxa are at the bottom of the diagram and their descendants are at the top. There are a number of reasons why Darwin might have done this, but it seems likely that part of the rationale relates to the paleontological argument which Darwin will be grounding in this diagram. The rock strata in which fossils are entombed are oldest at the bottom and newest at the top. Moreover, geological section diagrams of this time have a well-entrenched convention of iconically representing this ordering: old is down, new is up.[44] By echoing this iconic rendering of geological strata, Darwin prepares the way for his diagram to more effectively ground, not just taxonomic arguments, but also paleontological ones. Second, Darwin has increased the regimentation of the time dimension, adding horizontal lines numbered with Roman numerals. In addition to making diagram reference easier, this regimentation also prepares the way for Darwin's paleontological arguments. Instead of being forced to refer only to the labels of particular taxa, Darwin can also refer to the particular time period or geological stratum represented by a given horizontal rule.[45]

[44] For more on the visual conventions of contemporary geological sections and the jobs which they performed, see Rudwick 1976 and Porter 1977. See also Gross and Harmon 2014 (66-67).

[45] In addition to the changes in the diagram's visual conventions, Darwin has also eliminated from the verbal aspect of his argument the thought experiment about more-or-less moisture-loving plants. I am not certain why Darwin chose to do this, but it may be because the number of visual-verbal arguments supported by the diagram is larger in the *Origin*. Darwin may have decided that, rather than going for the specificity of the thought experiment, he should leave the discussions of taxon formation more abstract. Alternately, he may simply have felt that reference to specific traits like tolerance for moisture did not add much persuasive effect to his visual-verbal presentation.

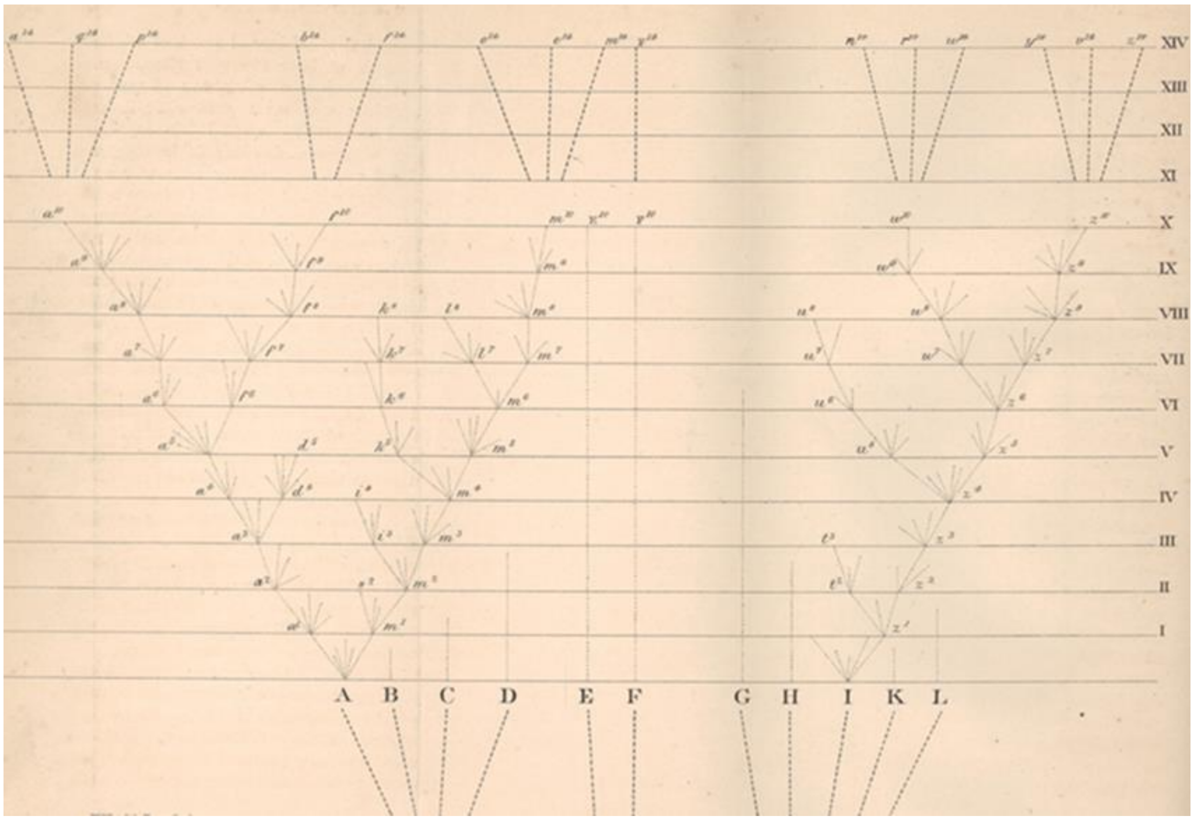


Figure 3.10: Darwin's tree diagram from *On the Origin of Species* (facing p. 117).

As in *Natural Selection*, Darwin first positions the diagram as a representation of the three key concepts of evolutionary change, extinction, and divergence of character (116), then as a representation of the creation of small taxa (116-124), then as a representation of the creation of larger taxa (124-25). There is an interesting shift, however, in the way that Darwin moves from the species formation argument to the higher-taxon formation argument. In *Natural Selection*, Darwin did this by increasing the scope of the diagram to include elements above and below—that is, before and after—the diagram itself. In the *Origin*, by contrast, Darwin does not do this. Instead, he keeps the focus of the diagram constant, instead changing the scale of the diagram. “In the diagram,” Darwin writes, “each horizontal line has hitherto been supposed to represent a thousand generations, but each may represent a million or hundred million generations” (124). If we expand the scale of the horizontal bands, then

> the forms marked a^{14} to p^{14}, those marked b^{14} and f^{14}, and those marked o^{14} to m^{14}, will form three very distinct genera. We shall also have two very distinct genera descended from (I); and as these latter two genera, both from continued divergence of character and from inheritance from a different parent, will differ widely from the three genera descended from (A), the two little groups of genera will form two distinct families, or even orders, according to the amount of divergent modification supposed to be represented in the diagram. (125)

Thus, if we allow each horizontal band to represent a thousand generations, then the tree diagram shows a single species ultimately giving rise to two genera or sub-families (123); but if we expand the scale such that each band represents “a million or a hundred million generations,” the diagram shows a single species giving rise to two families or orders. Since both processes are represented by the same visual, as Gross and Harmon note (2014), the implicit argument is that the two processes are identical in their structure and mechanics, with the only difference being the time period required (106). But this implicit argument also instantiates a topos which Darwin has employed since the B Notebook: Given a particular inference which works at one taxonomic level, try it out at a higher taxonomic level to see what happens. In addition to displaying the similarity of all taxon creation regardless of scale, then, Darwin’s diagram also instantiates the taxon-shifting topos developed in the B Notebook.

As in the earlier version of the tree diagram in *Natural Selection*, Darwin next uses the *Origin* diagram to suggest how the intermediate character of extinct organisms is explicable in terms of common descent from a shared ancestor. Darwin makes this point with reference to all the descendants of form A, which comprise three families on the left-hand side of the diagram (a14 to m14): "If, for instance, the genera a^1, a^5, a^{10}, f^8, m^3, m^6, m^9, were disinterred, these three families would be so closely linked together that they probably would have to be united into one great family, in nearly the same manner as has occurred with ruminants and pachyderms" (332). As in *Natural Selection*, particular extinct taxa are pointed out in the diagram and the consequences of their discovery by paleontologists are described to readers.

But the horizontal rules in this iteration of the diagram allow Darwin to develop this argument about the intermediate status of extinct forms more fully. Referring again to the three families descended from form A, Darwin asks his reader to imagine what would happen "If many extinct forms were to be discovered above one of the middle horizontal lines or geological formations—for instance, above No. VI.—but none from beneath this line" (332). The result, Darwin says, would be that "only the two families on the left hand (namely, a^{14}, &c., and b^{14}, &c.) would have to be united into one family;" the third family "would yet remain distinct" (332). By treating line VI on the diagram, not just as a past time period or a particular geological stratum, but as a horizon of our paleontological knowledge, Darwin addresses a potentially devastating objection to his theory: the fact that the fossil record provides only scant evidence of the common descent of large taxa. "As we possess only the last volume of the geological record, and that in a very broken condition," Darwin writes,

> we have no right to expect, except in very rare cases, to fill up wide intervals in the natural system, and thus unite distinct families or orders. All that we have a right to

> expect, is that those groups, which have within known geological periods undergone much modification, should in the older formations make some slight approach to each other; so that the older members should differ less from each other in some of their characters than do the existing members of the same groups; and this by the concurrent evidence of our best palæontologists seems frequently to be the case (333).

The increased regimentation of the time dimension in the *Origin* diagram, then, allows Darwin to simulate existing situations of paleontological ignorance. Doing this allows Darwin to posit a way for fossil evidence to indirectly confirm his theory: if we find groups of animals which become less and less dissimilar in older fossil beds, this suggests common ancestry. In short, Darwin's verbal-visual argument here instantiates his other B Notebook topos: When faced with a taxonomic puzzle, see if the puzzle can be resolved by positing a now-extinct common ancestor. Insofar as the relationship between "ruminants and pachyderms" is already being resolved along these topical lines, both Darwin's diagram and his implicit topos gain credibility: "Thus, on the theory of descent with modification," Darwin concludes, "the main facts with respect to the mutual affinities of the extinct forms of life to each other and to living forms, seem to me explained in a satisfactory manner. And they are wholly inexplicable on any other view" (333).

The final argument which Darwin anchors to the tree diagram occurs near the end of the *Origin*, and thus was not present as a visual-verbal argument in the unfinished book *Natural Selection*.[46] This argument does not just involve the depiction of core concepts of Darwin's

[46] Before this final argument in the *Origin*, Darwin uses his diagram to show why it should be that living things are always found nested in "groups subordinate to groups," a fact which, "from its familiarity, does not always sufficiently strike us" (412-13). Though this argument was present in a footnote in *Natural Selection*, it was not keyed to the diagram there—though the language used to make the argument is certainly suggestive: "we invariably

theory and how they interact to explain taxon formation or existing observations in paleontology: instead, it is a much broader argument about how naturalists should go about conceiving the classification of living beings. Rather than providing concepts or explanations, in other words, this final argument gives naturalists a comprehensive way of thinking about "the natural system," that is, the overarching set of relationships governing all life on earth (420). Darwin initiates this argument by suggesting that, without quite realizing it, naturalists have been unconsciously seeking a consistent and effective way to classify living things which only Darwin's theory, not creationism, can provide: "the characters which naturalists consider as showing true affinity between any two or more species, are those which have been inherited from a common parent, and, in so far, all true classification is genealogical; that community of descent is the hidden bond which naturalists have been unconsciously seeking, and not some unknown plan of creation" (420). Darwin then illustrates this point by describing the relationships among different labeled taxa in his diagram, concluding that, though the descendants of a given species may all belong to a particular taxon because of common descent, this taxon may be either a genus or a family or an order, depending on the amount of evolutionary change which these descendants have had since arising from their common ancestor: "Thus, on the view which I hold, the natural system is genealogical in its arrangement, like a pedigree; but the degrees of modification which the different groups have undergone, have to be expressed by ranking them under different so-called genera, sub-families, families, sections, orders, and classes" (422). Having shown how the core concepts of his theory work together to explain both taxon formation and observed puzzles in the relationships among living and extinct organisms, Darwin's final visual-verbal argument allows him to suggest a guiding idea for the classification of living things: use common descent

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see organic beings related to each other in groups within groups—or *somewhat like the branches of a tree sub-dividing from a central trunk*" (1975, 164n., emphasis added).

to determine taxonomy, use degree of evolutionary diversification to name taxonomic levels. Darwin's diagram has thus grounded a series of visual-verbal arguments in the *Origin* which move from descriptive to explanatory to programmatic. Extending the visual-verbal rhetorical strategy of *Natural Selection,* Darwin has repeatedly returned his readers to the same diagram so that the core concepts of his theory, the explanations derived from these core concepts, existing scientific observations, and projects in which naturalists are currently engaged are connected together into one coherent representation of nature. This representation, moreover, also instantiates both the visual conventions and the novel reasoning strategies which Darwin began developing with the aid of his early tree diagrams in the B Notebook.

Conclusion

Darwin begins his process of visual-verbal invention in the B Notebook as a way to clarify his own thinking and derive novel insights about nature which might later be elaborated into a coherent theory of evolution. In the process, however, Darwin also develops ways of visually representing aspects of nature (extinct organisms, nested branchings, etc.) and novel reasoning strategies which facilitate the development of novel inferences (assuming an extinct common ancestor, shifting an inference up a taxonomic level). With *Natural Selection,* Darwin has largely solidified the theoretical claims about nature which he wishes to make, as well as the reasoning strategies useful for solving problems from within his theoretical framework. He now moves to a new stage of inventional work: the development of a rhetorical strategy by means of which he can communicate his now largely completed theory to his readers. Because Darwin wishes to use his diagram to ground a number of visual-verbal arguments scattered throughout the course of a book-length monograph, reference to particular diagram-elements must be as simple as possible. To facilitate this, Darwin borrows visual conventions from geometry. Between B Notebook diagrams and the *Origin*, then, Darwin has moved from theoretical speculation to rhetorical invention to the implementation of a coherent visual-verbal rhetorical strategy. His visual representation practices and his overall rhetorical strategy then evolve together, so to speak, until he has produced a series of compelling arguments all anchored in the same diagram. This single diagram is the result of a lengthy, iterative, and strategic process of revision by which a crude family tree comes to be a sophisticated mixture of varied visual conventions intended to carry out a number of distinct visual-verbal rhetorical tasks. By tracing this complicated inventional path, we see how changing rhetorical purposes, rhetorical strategies, representational practices, and knowledge claims can produce, over time, a single knowledge representation of great rhetorical sophistication and complexity.

Chapter Four: Mathematical Invention

Daniel Dickson-LaPrade

> . . . on any straightforward reading, most theories are contradicted by the vast majority of the data points that are gathered to test them.
>
> —McAllister (1997, 217)

> Yet it must be recollected that, so far as our experience has hitherto gone, every advance towards generality has at the same time been a step towards simplification. It is only when we are wandering and lost in the mazes of particulars. . . that nature appears complicated:—the moment we contemplate it as it is. . ., we never fail to recognise that sublime simplicity on which the mind rests satisfied that it has attained the truth.
>
> —Herschel (1831, 270)

In previous chapters, we have examined how Darwin used list-making and diagrams to generate plausible theoretical innovations, develop these innovations more fully, and present them to scientific audiences. In this chapter, I extend my analysis of Darwin's inventional practice to mathematics. As in previous chapters, I will use a particular inventional process—Darwin's development of an explanation for the terraced cliffs along the Argentinian coast—to understand how his theoretical and rhetorical innovations were developed, and how they related to one another. I will trace Darwin's theoretical and rhetorical invention by examining how he shifted from one modality to another, using cross-modal perspectivizations to collect knowledge into one representation which could then be used to generate novel conceptual insights. As with Darwin's list-making and diagrams, I hope to show how mathematics helped Darwin to produce a novel scientific explanation as well as the persuasive, multimodal discourse used to make that explanation plausible for his readers.

It would seem that nothing could be less rhetorical than mathematics: numbers do what numbers do no matter what they are being used for, and mathematical operations work out the same way regardless of who is doing the operating. Recently, however, scholars have begun to demonstrate that there are important rhetorical dimensions to mathematics. This work has shown, among other things, that the value, scope, and legitimacy of mathematical concepts and procedures are not obvious a priori, but rather must be argued into place. James Wynn (2012), for example, shows how naturalists and mathematicians like Mendel, Darwin, Francis Galton, Karl Pearson and R. A. Fisher had to argue for various types of mathematization in biology. Before these rhetors had their say, the study of life had very little to do with numbers. Wynn shows that only by their argumentation did math and statistics come to occupy the privileged place in life sciences which it holds today.

Another rhetorical aspect of mathematics involves the development of mathematical concepts which have no empirical basis, and cannot be easily depicted using existing canons of mathematical representation. Such concepts depend, at least in the early stages of their development, on rhetoric, which gives them form and shows their utility. Reyes (2006), for example, depicts attempts by Newton and Leibniz to present infinitesimals as a mathematically useful concept. But infinitesimals have no empirical existence and no obvious way to be represented in then-existing canons of mathematical representation. On Reyes' account, infinitesimals are "*only rhetorically substantial*" (164). Newton and Leibniz had to verbally describe what they are and how they are useful, since they cannot be pointed out in nature. Such concepts may therefore require persuasive discourse in order to be available at all as a conceptual possibility for users of mathematics.

A third aspect of the rhetoricality of mathematics will be the focus of the current chapter. This is the *inventional* aspect of mathematics. Little and Branker (2012), for example, describe how William Hamilton attempted to argue for the legitimacy of imaginary numbers—multiples of the square root of -1—in spite of the distrust which mathematicians in the early 19th century felt toward mathematical symbols that are 1) not easily represented geometrically and 2) have no empirical referent. Hamilton did this by using analogy. Rather than basing arithmetical operations on quantity, Hamilton suggested basing them on time. Thus, zero does not mean nothing; instead, it means "coincident." A negative number is not a negative quantity of something; rather, it is a moment which happened before the present moment (283). All of the arithmetic operations available with ordinary algebra would also work with Hamilton's new, time-based model, but Hamilton was able to use the time analogy to at least mitigate the challenge of thinking about imaginary and complex numbers. By moving from a quantity-based model to a time-based model of real numbers, Hamilton could produce an algebra with room for the imaginary numbers. On Little and Branker's account, "analogy did not function alongside Hamilton's mathematics, nor was it exegetical to it. It was not enlisted to solve a particular problem within an already established mathematical framework" (288). Instead, "analogy served as a kind of mathematical reasoning itself, underlying and structuring the development of Hamilton's technical argument and the new mathematical reality that his argument brought into ideational existence" (288). By using mathematical analogy as an inventional tool, then, Hamilton could produce a new approach to algebra and argue for its utility.

Wynn (2012) also describes the inventional possibilities of mathematical analogy in his discussion of Gregor Mendel's hybridity experiments with pea plants. Mendel hypothesized that the rules of probability involved in, say, flipping a coin would shed light on the rules of probability involved in the inheritance of traits. Wynn shows how this analogy structured Mendel's experimental design—for example, Mendel selected traits for observation which were clearly binary and which remained stable and pure across many crossings (84-85). Further, Mendel also used this analogy in the presentation of his experimental results, albeit with the terms reversed: the first half of his landmark paper is dedicated to presenting experimental results, while the second half is used to build these results into probabilistic laws of trait inheritance (87-96). In both his experimental design and in his presentation of results, then, Mendel uses an analogy from a well-understood area of mathematics to structure both his investigation and his description of trait inheritance.

Investigations into the rhetoric of mathematics by Little, Branker, and Wynn all show an approach to mathematical invention congenial to my own: a particular inventional move is shown to aid in the construction as well as the presentation of a mathematical innovation. In both cases, however, the inventional move employed is a mathematical analogy, while the resulting innovation is itself a mathematical structure or operation. In the present chapter, I attempt to move the investigation of mathematical invention in a very different direction. Specifically, I will be examining the way in which a scientist process, analyzes, and manipulates numerical data to make it simpler and more tractable so that facts about nature can emerge from it. Whether it is a psychologist investigating short-term memory by subjecting experimental data to statistical analysis or a physicist culling the most revealing bubble chamber photographs from an enormous stack, I will be arguing that the iterative and strategic re-representation of numerical data is a process of rhetorical invention—indeed, that it is merely a special case of the iterative and strategic re-representation of all sorts of knowledge used in the production of persuasive discourse more generally. The uses to which scientists put data are inventional, and this inventional process generates both theoretical innovation and persuasive presentation.

I will examine Darwin's measurements of the elevations of terraced coastal cliffs in Argentina. I will show how Darwin made sense of his measurements by 1) borrowing a reasoning strategy from the geologist Charles Lyell, extending it to the Argentinian context and altering it to suit his specific investigative needs; and 2) combining measurement data together into cross-modal perspectivizations which allowed him to more easily detect meaningful patterns in this data. Having completed his trip down the Argentinian coast and up the Rio Santa Cruz, Darwin had a Lyellian explanation for the cliffs he was seeing, a mass of chaotic mathematical data, and a pool of multimodal representations of that data which he used to clarify his understanding of the cliff system.

But Darwin's data did not tidily fit his Lyellian account of Argentina's cliffs. Some data-points seemed to fit this account well, while others did not. As he sharpened his model, Darwin had to find ways to improve the fit between his data and his model. Here again, Darwin constructed cross-modal perspectivizations which allowed him to explain or alleviate discrepancies between data and model. Having gotten a satisfying fit between data and model, Darwin could then repurpose prior perspectivizations as part of the multimodal argument which he published to present his model to readers. In short, Darwin tried to make his data more tractable and orderly, and to improve its fit with the model which he was developing as part of his investigation of Argentina's geology. This repeated, cross-modal re-representation of knowledge was a process of rhetorical invention, and this process generated both theoretical innovation and (after further revision) audience-directed argumentation. In Darwin's investigative and rhetorical practice, then, mathematical data and operations were irreducibly inventional and rhetorical, both in Darwin's development of his scientific model and in the presentation of that model to his readers.

Darwin's Geological Data

Darwin's geological investigations, long overshadowed by his work on evolution, have only recently received sustained scholarly attention.[47] It is surprising to realize, then, that it was primarily as a geologist that Darwin was known during the late 1830s and the 1840s. Throughout most of Darwin's five years on board the *Beagle*, his geological notes outnumbered his notes on biological subjects—in some years by more than ten to one (Porter 1985, 984). By 1838, he was not only a respected member of the Geological Society of London, but was also elected as one of the Society's two Secretaries (Rhodes 1991, 197; Herbert 2005, 92-93). Upon his return from the *Beagle* voyage, a decade of sustained geological activity followed, culminating in three book-length monographs in the mid-1840s. Darwin's pioneering research on plutonic and metamorphic rocks, his important paleontological discoveries, and his largely accurate explanation of origins of coral atolls all make Darwin one of the most historically significant 19th century geologists (Martínez, Rabassa, and Coronato 2009, 98; Herbert 1985, 493-94).

[47] Before researches by Herbert (1985) and Porter (1985), there were very few articles or book chapters relating to this subject, while Herbert (2005) is the first book-length work to deal with Darwin's geological investigations.

But even more important than his concrete discoveries and theoretical explanations was the role which Darwin played in revolutionizing geology in the years before 1840. Darwin's work gave respectability to the doctrine of uniformitarianism—the idea that cataclysmic events are not typically required to explain the facts of geology, and that very gradual forces working through long periods of time work better as explanations. One of the only geologists holding this unpopular view in the 1830s was Charles Lyell (Herbert 1985, 502; Rhodes 1991, 196). Rhodes (1991) argues that Lyell's approach to geology "gave Darwin a methodological tool and a conceptual framework, influencing not only his geological observations and conclusions, but also, ultimately, his views on the origin of species" (195). In a letter to his cousin William Darwin Fox from the *Beagle*, Darwin wrote "I am become a zealous disciple of Mr Lyells views [sic], as known in his admirable book.— Geologizing in S. America, I am tempted to carry parts to a greater extent, even than he does" (1 July 1835). In the geological works which he published upon his return, this is exactly what he did, extending Lyell's uniformitarian explanations of small geological formations to entire continents, including the continent of South America (Herbert 2005, 243).

The "admirable book" that so impressed Darwin was Lyell's *Principles of Geology*, published in three volumes between 1830 and 1833. Darwin carried the first volume onto the *Beagle* in 1831, encouraged by John Stevens Henslow, one of his mentors at Cambridge, to "get and study the first volume of the *Principles*. . ., but on no account to accept the views therein advocated" (Darwin 1985, 101). On the frontispiece of the first volume was a picture of the pillars of the Temple of Serapis near Naples. These pillars showed evidence, midway up their sides, of boring by marine organisms. Since a cataclysmic upraising of the columns from the ocean would not have left them standing, some geologists of the time suggested local causes, such as the damming up of water nearby (Herbert 2005, 152-53). Lyell, however, suggested that a slow, gradual elevation of the land under the temple would explain the odd boring (1830, 449-59). Faced with an effect typically only found under the ocean, Lyell used a gradualistic logic to explain its existence far above the ocean's surface.

In 1832, Darwin faced a geological problem of a similar nature at St. Jago (São Tiago) in the Cape Verde Islands. About thirty or forty feet above the shoreline at St. Jago was a straight, horizontal band of white rock of a sort that would have been more reasonable to find at or below the waterline. But how could this layer of rock have been raised so far above the shoreline without disturbing it and the strata above and below it? Like the Temple of Serapis, this formation could be explained by the gradual elevation of the shoreline over long periods of time (Secord 1991, 151-52; Herbert 2005, 152-54). The reasoning strategy which Lyell had used to explain the boring of marine organisms above the waterline was now adapted by Darwin to explain the horizontal band of white rock at St. Jago: seeing an ocean-related phenomenon well above the ocean's surface, and seeing that a catastrophic explanation would cause disturbances not visible in the formation, see whether a gradual raising of the land out of the water will explain the formation. This reasoning strategy was to be essential to Darwin's geological investigations throughout Argentina.

St. Jago represented for Darwin a watershed moment in his career as a scientist: the first time that he was able to produce new knowledge about a geological formation, and to produce it using Lyellian principles (Rhodes 1991). Writing about the event near the end of his life, Darwin pinpointed the importance of St. Jago in his development as a scientific investigator: "I am proud to remember that the first place, namely St. Jago, in the Cape Verde Archipelago, which I geologized convinced me of the infinite superiority of Lyell's views over those advocated in any other work known to me" (1958, 101; see also 77). Lyell had provided Darwin with the tools to perceive geological formations in terms of the gradual elevation and subsidence of land, tools which would be essential for his geological work in South America.

One of the primary goals for *Beagle*'s voyage was to carry out a geological survey of the eastern coast of Argentina (Herbert 2005, 17, 161). Darwin worked together with the ship's officers to generate detailed measurements of the heights of the terraced cliffs found all the way down the coast (Herbert 2005, 160). This cliff measurement began shortly before Christmas 1833, when the *Beagle* arrived at Port Desire (Puerto Deseado). Over the next four months, the measurement of cliffs along the coast (and other scientific labors) took Darwin and the crew down to the city of Santa Cruz, and about a hundred miles up the Rio Santa Cruz. By May 18834, having measured the terraced cliffs from Port Desire down to the Rio Santa Cruz, Darwin had developed a body of numerical data and a model for what had caused Argentina's stepped coastal cliffs.

When the *Beagle* first arrived at Port Desire, Darwin was struck by a series of plateaus along the coast, the lowest of which rose about 100 feet above the sea. With the aid of a barometer brought specifically for his surveying work, Darwin set about measuring the heights of the terraced cliffs at Port Desire. Of course, the process of measuring heights with a barometer was full of possibilities for error: instrument problems, operator error, and momentary fluctuations of temperature and air pressure could all introduce spurious results. Moreover, even for plains as level as the ones at Port Desire, there is variation in the height of the land. For this reason, it was necessary for Darwin to take several measurements of a given plain in order to produce a robust estimate of the plain's average height. Taking multiple measurements of these elevations was necessary anyway given the importance which contemporary scientists gave to mathematical precision in both measurement and the statement of natural laws. We have already seen the importance of John Herschel's (1831) influence on Darwin. Herschel noted that adequately precise scientific measurement requires the scientist to work "by repeating the measurements a great number of times, and under a great variety of circumstances, and taking a mean of the results, when errors of opposite kinds will, at length, compensate each other" (97; see also 161). Herschel actually used barometric measurement as an example of the importance of such large and varied measurements in scientific investigation (215-16).

After collecting data on the second-highest cliff at Port Desire, Darwin arrived at the following measurements: 247 feet, 261 feet, 245 feet, and 253 feet. On the basis of these height measurements, Darwin settles on a height estimate for this range as between 245 and 255 feet. Similarly, Darwin arrives at an elevation of 320 to 330 feet for the next-higher plain (CUL-DAR 33.236v). Darwin now has a simplified representation of the cliff-heights at Port Desire: a low cliff of 100 feet, a middle cliff of 245-255 feet, a high cliff of 320-330 feet, and a still higher cliff further back from the shore whose height he did not have the opportunity to measure. A dozen specific data points are re-represented as three heights.[48]

Even on the highest of the Port Desire cliffs, Darwin noticed the shells of marine mussels, many of which still had a slight blue color. This, along with certain mineralogical peculiarities, suggested to Darwin that these broad, flat plains must have originally been below

[48] Actually, the picture is even more complex than this. Just to get a single height measurement, Darwin had to measure the temperature, barometric pressure, and degree of mercury expansion at a known elevation, then do these same three measurements for the elevation being determined. Having gotten these six measurements, Darwin then had to consult three distinct multi-page tables and subject his measurements and table results to a total of nine distinct arithmetical calculations. Thus, a single cliff-height measurement like 245-255 feet arose from four distinct processes of measurement; each of these processes of measurement, in turn, originated from half a dozen particular measurement-actions. See Jones [1802] for details.

the surface of the ocean (CUL-DAR 33.238-39; Darwin (1831-36), 408).[49] Darwin found the elevation of such large, flat expanses of land shocking: “It is surprising to reflect that these plains, which are so level, should have been subject to a force so enormous, as to upheave them from the bottom of the sea” (CUL-DAR 33.236). Darwin has found at Port Desire a geological phenomenon which would be expected under the sea, but which is now above the waterline. Moreover, there is no evidence of a sudden cataclysm pushing the land upward. Darwin has all the ingredients needed to apply Lyell’s gradualistic reasoning strategy to explain the shells and mineralogy at Port Desire.

Previously at St. Jago, Darwin was able to apply Lyellian gradualism rather straightforwardly to explain a geological formation never seen by Lyell. This same approach likewise seemed applicable to the flat, terraced cliffs at Port Desire, but with an important difference: while the white band of rock at St. Jago, like the tiny holes in the columns at the Temple of Serapis, could be explained by a single elevation of the coastline, the multiple terraced cliffs of Port Desire could not. Darwin must expand Lyell’s gradualistic reasoning strategy to account for the *series* of flat cliffs with marine mussel shells on them. He does this by assuming that each of the Port Desire cliffs is the result of an elevation of the coast, with the pause between elevations allowing the ocean waves to turn the new cliff’s gradual slope into a steep base: “The difference of 75 feet, between the 250 & 325 plains I am strongly inclined to attribute to two elevations; although as there are no proofs in other places on the coast of such a plain it must remain doubtful” (CUL-DAR 33.244). Since Darwin had not previously seen such obvious stepped cliffs on the coasts of Brazil or Uruguay, and since the cliffs he had observed on

[49] The notation CUL-DAR refers to the Darwin papers at the Cambridge University Library. These documents are available on John van Wyhe’s *Darwin Online* website <darwin-online.org.uk>. All images in this chapter from Darwin’s notebooks are reproduced from Wyhe’s presentation of Cambridge’s scanned pages.

the more northerly parts of the Argentinian coast were much less pronounced, the idea of two or more distinct elevations does not seem well supported except at Port Desire.

In January 1834, the *Beagle* continued further south to Port St. Julian (Puerto San Julian). The mineralogical features of this cliff system were very similar to those at Port Desire (CUL-DAR 33.248). Moreover, Darwin saw a very similar series of stepped cliffs, the lowest of which seemed to be a continuation of the 100-foot plain at Port Desire (CUL-DAR 33.244). Moreover, this low cliff had some of the same species of marine mussels, some of which still maintained the blue color that Darwin saw as a sign of relatively recent elevation of land from the sea (CUL-DAR 34.47v). The lack of “proofs” of multiple elevations on the Patagonian coast was thus resolved: “so many facts require repeated elevations” of the entire eastern coast of Patagonia, Darwin decides (CUL-DAR 33.248). Though Darwin’s measurements of the Argentinian coast began as part of a geological survey, his observations at Port Desire made him attentive to past elevations of the land, and suggested to him that Lyell’s gradualistic reasoning strategy be extended to involve, not just single elevations, but series of elevations. Now, at Port St. Julian, Darwin’s expansion of Lyell’s strategy seems to explain, not just the cliffs at Port Desire, but the geological features of a stretch of Argentinian coastline stretching over 100 miles.

Continuing south along the coast, Darwin and a team of *Beagle* officers visited Santa Cruz in April and traveled over 100 miles up the Rio Santa Cruz. Here again Darwin saw the same mineralogical layers he found at Port Desire and Port St. Julian, and the same mussels at elevations of up to 400 feet. And here again he found a series of stepped cliffs (CUL-DAR 34.47, 34.99, 34.105-06, 34.107-110v). Darwin is thus encouraged to believe that this cliff system is a continuation of the one he has already seen at Port Desire and Port St. Julian. This cliff system is even more visually evident and striking than the ones at his previous two stops, in part because there are *two* sets of cliffs here—one on either side of the Rio Santa Cruz, with similar cliff elevations on each side. Starting about 55 miles from the mouth of the river, the cliff system becomes particularly obvious to the eye: “There are often 5 sets of plains, (besides the bed of river),” Darwin writes (CUL-DAR34.99v).

Previously, Darwin has dealt with the heights of individual cliffs at particular locations. Sailing up the Rio Santa Cruz, Darwin’s representational task is made more complicated by two factors: first, there are two series of cliffs flanking the river, rather than just a single set; and second, the heights of the individual cliffs in each series are not constant, but vary along the river. Merely listing discrete measurements will not provide rich enough detail for later examination, so Darwin begins to produce diagrams which encompass the river’s dual cliff system as a whole. Labeling the plains on the southern bank of the river B, C, D, and E and the plains on the northern bank Bn, Cn, Dn, and En, Darwin sketches their appearance in a diagram which will later be revised for publication in 1846 (see Figure 4.1). But an important aspect of the Rio Santa Cruz cliff system is omitted from this simplified visual presentation: the great variation in the heights of these plains as Darwin and his party traveled up the river. The northern C cliff, for example (marked “Cn” in figure 4.1) was measured at 330 feet near the mouth of the Santa Cruz, but rose as high as 639 feet further inland (CUL-DAR 34.104; see also Figure 4.2, below). Similarly, the D cliff rose from 558 to 882 feet (CUL-DAR 34.103-103v). Unlike the plains at Port Desire and Port St. Julian, the cliff system along the Rio Santa Cruz was much less level and uniform—and its measurement data was much more complicated and chaotic. Darwin thus faces two contradictory forces in dealing with the river system: on the one hand, the cliffs on both sides of the river have a visually striking terraced quality, even more so than at previous stops along the Argentinian coast; on the other hand, each cliff shows much more height variation than the cliffs at Port Desire and Port St. Julian.

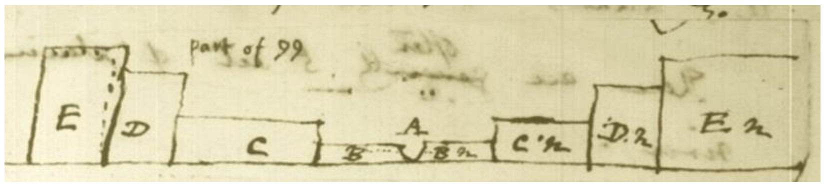


Figure 4.1: Darwin's sketch of the cliffs flanking the Rio Santa Cruz (CUL-DAR 34.99). Cf. Figure 4.9.

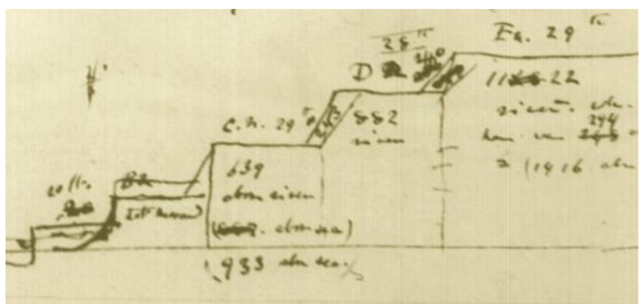


Figure 4.2: Measurements of cliff elevations along the northern shore of the Rio Santa Cruz taken by Darwin on April 29, 1834 (CUL-DAR 34.103). Cf. Figure 4.9.

The cliffs at Darwin's previous stops along the Argentinian coast could be plausibly explained by a series of elevations of the land out of the sea. The Rio Santa Cruz cliffs, however, flanked a river; they were not coastal cliffs. Normally, a series of stepped plains flanking a river would most plausibly be attributed to erosion caused by the river itself. But considering the similarity of the cliffs at Port Desire, Port St. Julian, Santa Cruz, and along the river, Darwin is attentive to other possibilities. The river could not have caused this double cliff system, Darwin decides, because of the small amount of rainfall, the amount of foliage close to the banks of the river, and the rarity of flooding (CUL-DAR 34.104-05). Further, the gravel on many of these cliffs was cemented together by "white aluminous matter," of the sort found in an undersea shingle bed—not something that a river would do (CUL-DAR 34.104-05). Add to this the presence of marine mussel shells at elevations of up to 400 feet, and an alternative explanation was clearly needed: "Taking all these facts into consideration there cannot be any doubt, but that the sea has excavated this great valley"—the sea, and not the river (CUL-DAR 34.106).

The problem with such an account is that the sea is cut off from the Rio Santa Cruz valley by the Andes. If Darwin is to explain the Rio Santa Cruz cliffs using the same Lyellian reasoning strategy that worked at Port Desire and Port St. Julian, he must somehow find a plausible account according to which the river at one time connected the Atlantic and Pacific Oceans, such that the cliffs flanking the river at one time flanked a channel. According to such an account, the Rio Santa Cruz was at one time an ocean strait, rather like the Strait of Magellan further south. Darwin could get this sea-strait account by extending his hypothesis about multiple elevations along the eastern coast of Argentina to encompass the entire southern portion the continent. Darwin noted that even today, the Andes is crossed by the ocean further south at Obstruction Sound. Moreover, toward the end of the excursion up the river which Darwin took with a retinue of *Beagle* officers, "there is a remarkable gap in the mountains, which was noticed by everyone as quite breaking the continuity of the chain" (CUL-DAR 34.106). Given these observations, Darwin feels justified in extending his multiple-elevations hypothesis to include, not just the eastern coast of Argentina, but also the Rio Santa Cruz and even the Andes as well: "when the land was depressed from 1000 to 2000 feet an inlet of the sea would cross the Andes" (CUL-DAR 34.106). As the southern part of Patagonia went through a series of elevations, "there can be no doubt the action of currents would prolong & deepen the channel from the break in the mountain", thus resulting in the series of stepped plateaus along the Rio Santa Cruz (CUL-DAR 34.107).

In spite of its apparent difficulties, then, the multiple-elevations model which Darwin developed in Port Desire and Port St. Julian, properly expanded, applies equally well to the Rio Santa Cruz valley and even as far westward as the Andes Mountains: the entirety of Argentina, and not just a section of the coast, has gone through a series of stepwise elevations. This model accounts for the stepped plateaus found along the eastern coast and in the river valley, the mineralogical peculiarities found throughout Argentina, and the marine mussel shells found at elevations of up to 400 feet. Further, the multiple-elevations model receives independent confirmation from the fact that only the ocean could have created the cliff formations flanking the Rio Santa Cruz, since the small, sluggish, seldom-flooded river could never have created such cliffs. Darwin has thus taken Lyell's reasoning strategy and extended it in two ways. At Port Desire and Port St. Julian, he has made it account for *successive* elevations, rather than just a single elevatory movement; and along the Rio Santa Cruz, he has extended this multiple-elevations model to encompass the entirety of Argentina, rather than just a single location as at St. Jago.

By the time he has concluded his trip up the Rio Santa Cruz, then, Darwin has developed a coherent explanation for the stepped cliffs found throughout Argentina, an explanation which he will be able to test further by sailing through the Strait of Magellan and continuing his surveying work up the coast of Chile. But Darwin has also developed two other resources to help him in further rounds of inventional work as he refines his theory and prepares it for publication. First, Darwin has produced, with the aid of *Beagle* officers, a body of numerical data from his measurement of elevations along the coast and up the Rio Santa Cruz. Unfortunately, many of Darwin's numerical data did not unambiguously support his simple model. The varying cliff heights along the banks of the Santa Cruz, for example, made it difficult to ensure any connection with elevations at the other locations which Darwin had visited. Darwin's second resource, however, can help him with this difficulty: Darwin has begun to produce a pool of multimodal data representations with which he has tried to order his observations for further rounds of processing and analysis. Thus, as the *Beagle* sailed down to Tierra del Fuego in May 1834, Darwin worked intently to clarify and complete his model of South American land elevations.

Squaring the Model and the Data

As the *Beagle* sailed down to Tierra del Fuego, the crew took trigonometric measurements of the stepped cliffs at Gallegos and the Coy Inlet (see Figure 4.3). From May 12, 1834 on, Darwin took these measurements, along with the data he had already collected during the previous four months along the Argentinian coast, and tried to simplify them, clarify them, and improve their fit with his multiple-elevations model of the Andes, the Rio Santa Cruz, and Argentina's eastern coast. [50] Darwin used three strategies to perform these tasks. First, Darwin attempted to link similar height measurements at different locations, treating them as portions of

[50] For the dating of Darwin's inventional process in May 1834, I here rely on the "Concordance to Darwin's *Beagle* Diaries and Notebooks" found at the *Darwin Online* website (http://darwin-online.org.uk). Unfortunately, the notebook pages which reveal this process do not supply specific dates. Though it is clear that this entire process took place between May 12 and June 1, 1834, and though we can determine which notebook pages were filled in what order, it is not possible to provide precise dates for the various steps in this inventional process.

the same cliff. Second, he re-represented his numerical data to himself in a variety of forms, such as diagrams and lists, in an attempt to determine which cliff-heights could reasonably be considered portions of the Patagonia-wide, comprehensive cliff system which he was developing. Third, because Darwin's height measurements were never quite identical from one location to the next, Darwin had to find plausible evidence or explanation to justify treating such not-quite-identical measurements as equivalent. By the time the *Beagle* landed in Port Famine (Puerto Hambre) in Tierra del Fuego on June 1, 1834, Darwin had developed 1) a comprehensive list of cliff-height categories which he felt were represented along the Argentinian coast and along the Rio Santa Cruz; and 2) a list of locations where measurements fitting each of these cliff-heights could be found. Having determined the number and elevations of cliffs in the Argentinian cliff-system, Darwin had a plausibly, empirically supported model of this system which could be subsequently presented to a scientific audience.

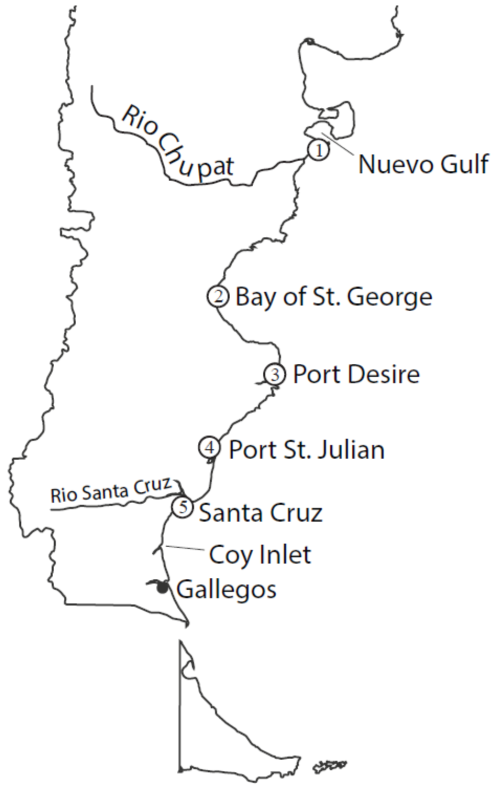


Figure 4.3: Important locations where Darwin measured coastal elevations along the Argentinian coast. Circled numbers correspond to figure numbers in Darwin (1846), discussed in the next section. Map prepared by Alicia Zahrai Keys.

Darwin's first step in clarifying and completing his Argentinian cliff-system model is to match relatively close cliff-height measurements from different locations, under the assumption that successive and uniform elevations extend throughout Argentina. Thus, Darwin refers to prior measurements showing a "250 ft plain" which extends "from P. Desire to N. Bay of St. George 170 miles [long]" (CUL-DAR 34.41A; see Figure 4.4). Darwin also lists several other locations with a similar cliff-height measurement: "C. Blanco 250. North [Bay of St.] George 250. S. of New Bay 200 to 220" (CUL-DAR 34.41A). Similarly, Darwin notes the presence of a plain between 90 and 100 feet in elevation at Port Desire, Port St. Julian, and New Bay (Nuevo Gulf; CUL-DAR 34.41A). These listings of similar cliff-height measurements allow Darwin to gather previously scattered data-points from disparate locations and re-represent them together in a new form—sentences of prose which make explicit the connections among these data points. In short, Darwin's lists of locations with similar cliff-heights is a cross-modal perspectivization. By listing similar cliff-height measurements taken in different locations, Darwin hopes to arrive at a coherent model of the continent-wide system of cliffs. As we will see, however, these perspectivizations themselves will also serve when Darwin comes to present this coherent model to a scientific audience.

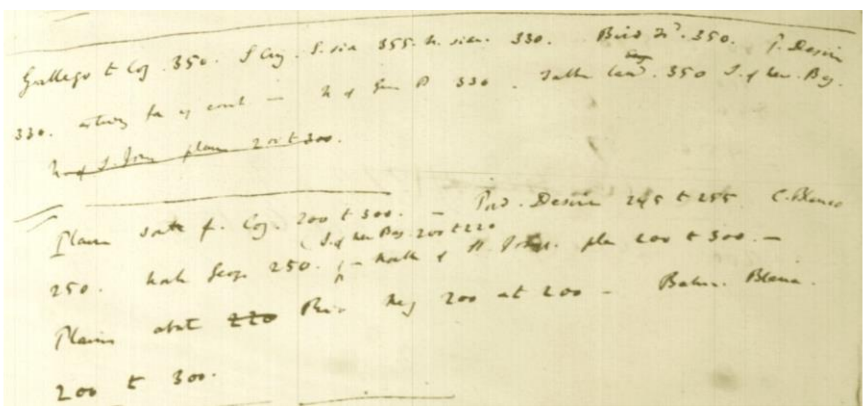


Figure 4.4: Darwin's measurement-matching (CUL-DAR 34.41A). The top line of text reads "Gallegos to Coy 350. S. Cruz. S. sea 355 N. side. 330. Bird Is[d]. 350. P. Desire 330." The portion of text below the horizontal line performs similar measurement-matching for a plain of "200 to 300" feet tall found at the Coy Inlet, Port Desire, and other locations. Cf. Figures 4.10 and 4.11.

Having matched similar height-measurements across locations, Darwin then takes heights consistent across locations and lists them—"90-100," "220 to 255," and so on (see Figure 4.5).[51] After listing these relatively stable ranges of measurements, Darwin numbers them from one to eight. He has now moved from 1) individual height measurements at individual locations to 2) lists of matching height measurements from distinct locations to 3) a simple list of height-ranges. He has thus produced a series of data representations culminating in a set of eight categories of cliff-heights. Having listed these measurement ranges, Darwin immediately re-inscribes the same information, on the same page, simplifying it slightly (see Figure 4.6). In this second list of consistent cliff-heights, the ranges are replaced with individual measurements: "90-100" feet becomes simply "100," "220 to 255" becomes "250," and so on. Having matched as many cliff-height measurements as he can from different locations, and having subsequently listed relatively consistent cliff-heights, Darwin now has a provisional list of height measurements which seem relatively stable over large areas of Argentina. These listed height elevations come, in Darwin's later invention, to be treated as coherent, discrete, natural entities.

[51] Darwin's usual practice in his geological notebooks was to first fill the recto folio, leaving the verso folio for later notes, addenda, and the like. (Chancellor). Darwin's listing of matching cliff heights has on its verso the columnar lists of measurements represented in Figures 4.5 and 4.6, strongly suggesting that the matching of cliff-heights came first, followed by the columnar lists.

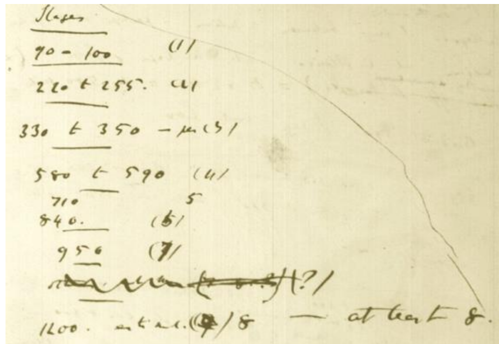


Figure 4.5: One of Darwin's lists of relatively consistent cliff-height measurement ranges (CUL-DAR 34.41Av). The text at the top reads "Stages," while the text at bottom reads "estimate 7/8—at least 8."

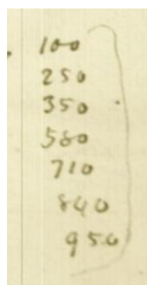


Figure 4.6: Darwin's second listing of relatively coherent cliff-height measurements (CUL-DAR 34.41Av).

The stability of these cliff-measurements in Darwin's invention is clear from a shift in the way that he refers to them. Specifically, the numerical measurements of cliff-heights gradually become labels instead. Thus, instead of "250 ft plain" or "350 ft plain," Darwin begins to use expressions like "250 & 325 plains" (CUL-DAR 34.62). This replacement of measurement with label becomes quite pronounced by the end of May: Darwin makes reference on a single notebook page to “the 840 range,” “the 240 plain,” and “[the] 330 plain” (CUL-DAR 34.61).[52] Having first turned dozens of measurements into a manageable body of average cliff-elevation measurements at individual, discrete locations, Darwin then matched measurement similarities across locations. Having re-inscribed these matches into a list of single height-measurements, Darwin now has a descriptional shorthand for naming particular cliffs across locations, regardless of slight variations in height between these locations, and regardless of the fact that not every cliff-height is found at every location. Darwin has thus repeatedly re-represented his messy and chaotic numerical data until he has developed patterns in his data, producing what he feels are stable, coherent, bounded natural entities.

But the variations in height measurements for these cliffs form an important inventional challenge for Darwin. He cannot merely invent or alter measurement data, but he also cannot ignore the sometimes pronounced variations in his corpus of measurements. For example, at Port St. Julian (marked 4 in Figure 4.3), Darwin found (among other things) a cliff measuring 90 feet and a cliff measuring 430 feet; at the mouth of the Rio Santa Cruz, however (marked 5 in Figure 4.3), Darwin did not find a 90-foot cliff, but did find a sloped cliff varying in height from 355 to 470 feet (CUL-DAR 34.48, 34.53-54). Though these two locations are less than 100 miles apart, no two cliffs at these locations have identical heights. Darwin must either find some plausible way to square this messy numerical data with his multiple-elevations model, or else he must somehow use the data to produce a model with more fidelity to his measurements.

Darwin addresses this inventional challenge by trying to provide plausible reasons showing why even non-identical height measurements in particular locations can plausibly

[52] Again, Darwin’s inventional process occurs on notebook pages which are not dated; however, the invention analyzed here appears to be a single, coherent stretch of work extending from CUL-DAR 34.40 to 34.64. Assuming that Darwin worked continuously on this invention between May 12 and June 1, the last pages of this section would presumably have been written sometime toward the end of May.

belong to the same cliff. Darwin begins by tackling the difference between the sloping cliff of 355-463 feet at Santa Cruz and the 430-foot cliff at Port St. Julian. Darwin uses two arguments to suggest that these two cliffs are actually same cliff, varying in height. First, he notes that one can visually trace the 330-350-foot cliff all the way to Port St. Julian: “This plains [sic] extends apparently without a break to the chain which forms the South of the Harbor of St. Julian; here however the elevation is 430 ft” (CUL-DAR 34.53). Second, Darwin notes that even at the mouth of the Santa Cruz, the 355-foot cliff gradually climbs over the course of several miles to an elevation of 460 or 470 feet. By analogy, Darwin suggests that a similar increase in height could explain the difference between the 355-foot cliff at Santa Cruz and the 430-foot cliff at Port St. Julian: “this rise [from 355 to 430 feet] is however to be accounted for, on the same principle viz its close proximity to the high series (as we formerly saw the <u>355</u> plain <u>460</u> at base of 710 plain [at Santa Cruz])” (CUL-DAR 34.53; see also CUL-DAR 34.61). Darwin thus uses his memories of the visual continuity of cliffs as well as analogical reasoning to argue for the similarity of even non-identical cliff heights. Using these tools, Darwin is able to confidently identify a 355-foot plain at Santa Cruz with a 430-foot plain at Port St. Julian.

But there is another challenge in squaring Darwin’s list of cliff-heights, the actual measurements at Port St. Julian, and the actual measurements at Santa Cruz. At Port St. Julian there is a 90-foot cliff and at Santa Cruz there is not. Darwin again attempts to provide reasons for thinking that this discrepancy is not fatal to his model. He does this first by suggesting that the actions of ocean waves may have eliminated any trace of the 90-foot cliff at Santa Cruz: “the South Point of St Julians is. . . level & about 90 or 100 feet above sea. — This is nearly the only low plain left on the coast, but as it exists it is probable that it formerly did [exist] extensively but [has] been eaten away” (CUL-DAR 34.61). Darwin reinforces the plausibility of this account by referring to his memory of the appearance of the land at Santa Cruz: "Some appearances at mouth of S. Cruz render this probable" (CUL-DAR 34.61). Thus, even though a cliff-height appears in one location and not another, this Darwin feels that he can plausibly explain this discrepancy, thereby removing its ability to disconfirm his model.

Indeed, having worked out some of these discrepancies, the extent and relative uniformity of certain cliff-heights strikes Darwin forcibly, giving him confidence in the correctness of his list of cliff heights: "the 350 plain is more distinctly to be traced, than perhaps any other one plain. . . probably had an original greater extent. — This one can be traced on the coast line, at intervals, & often of great extent for a distance of 550 miles. . . . the 250 [plain] can be traced over for a greater extent; from Port Desire to [Bahia] Blanca" (CUL-DAR 34.57). Darwin now feels that he has an impressive addition to geological knowledge that is worth sharing:

> Considering how little of the coast was examined, with geological views I think it is quite astonishing the agreement in height, in the <u>different</u> series of plains. widely apart. I feel quite convinced that the whole of the modern formations of S. America from above C. horn to near B. Blanca, a distance of nearly 1200 miles was formed by elevations, which acted over the whole of this space with nearly an equal force. (CUL-DAR 34.58).

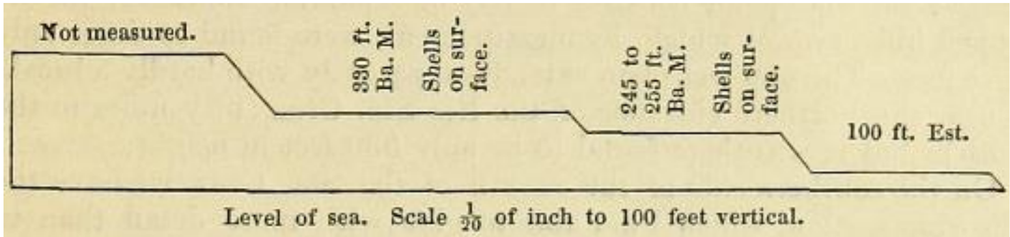
Thus, having matched obviously similar cliff-height measurements from adjacent locations (such as the 100-foot plain at Port Desire and the 90-foot plain at Port St. Julian), Darwin produced a list of cliff-heights which represent the coastal system of Argentina. Next, Darwin used his memory of what he observed in Argentina, analogical reasoning, and plausible accounts of past geological events (e.g., the washing away of a 90-100-foot cliff at Santa Cruz) to work out discrepancies in his height data, discrepancies which at first sight would seem to disconfirm a coherent Argentinian cliff system. Finally, Darwin listed cliff-heights with impressively long ranges, solidifying his confidence that these are natural entities revealing a past raising of the entirety of Argentina, rather than merely distinct cliffs in different locations. In short, Darwin has used successive re-representations of his numerical data to locate and clarify regularities and patterns, and to account for undesirable perturbations of or exceptions to those patterns. Upon his return from the *Beagle* voyage, Darwin is now ready to prepare for publication (among other things) his account of the Argentinian cliff system.

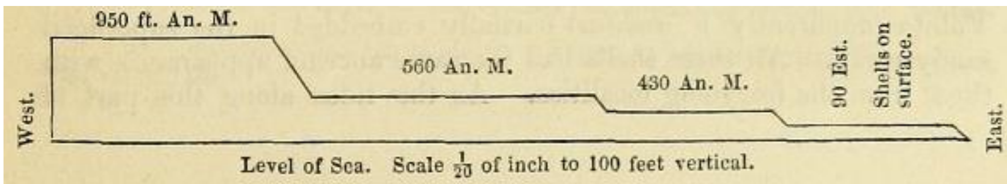
Darwin's Presentation of the Multiple-Elevation Model

Darwin presented his account of the Argentinian cliff system in the first chapter of his 1846 book *Geological Observations on South America*. In this chapter, Darwin begins with specific observations and measurements at specific locations—the Nuevo Gulf, Port Desire, the Rio Santa Cruz, and so on. Not until he has presented a great deal of specific detail about each of the locations does he let the reader know what he is using these observations and measurements to build: an account of multiple elevations of the entire southern part of South America which resulted in the stepped cliffs throughout Argentina and the metamorphosis of a sea strait into the Rio Santa Cruz. In moving from specific to general matters, Darwin employs multimodal data representations created during his invention on board the *Beagle*: diagrams of the cliffs flanking the Santa Cruz, the matching of similar cliff-heights at different locations along the coast, and so on. By not divulging the overall purpose of the treatment until near the end, Darwin is able to take the reader along the coast of Argentina, and along data representations which he produced subsequently, in a way calculated to resemble the conceptual path which made this multiple elevations model so intuitively compelling to Darwin himself. In short, Darwin provides his reader with some of the same experiences, insights, and data representations which first persuaded him of the accuracy and value of his model.

Darwin's first order of business is to visually present to readers the same terraced cliffs which he found so visually striking himself.[53] Darwin does this by providing a sequence of five illustrations which both display these cliffs and (in preparation for subsequent argumentation) strongly imply their underlying unity (See Figures 4.7 and 4.8). These five illustrations are keyed to the numbered locations in Figure 4.3, above. Darwin prefaces these illustrations by stating that "My object in giving the following measurements of the plains. . . is, as will hereafter be seen, to show the remarkable equability of the recent elevatory movements" (6). But Darwin does not mention that this "equability" means a series of successive elevations of the entire southern portion of a continent. Instead, he merely lets the visual similarity of the different diagrams speak for itself, occasionally pointing out places where a cliff in one illustration extends to the location represented by another illustration. Discussing the 430-foot plain at Port St. Julian, for example, Darwin notes that it "extends, apparently with hardly a break, to near the northern entrance of the Rio Sta. Cruz (fifty miles to the south); but it was there found to be only 330 feet in height" (8). Though Darwin does not explicitly tie together all these different cliff-heights into a coherent system yet, he is preparing readers for this synthesis later in the chapter.

[53] On the striking appearance of these cliffs, particularly at Port Desire and Santa Cruz, see Darwin (1846, 14-15).





Figures 4.7 and 4.8: Darwin's (1846) illustrations of the terraced cliffs at two of the five locations presented in his first five figures: Port Desire and Port St. Julian (7). "Ba. M." in these visuals refers to Darwin's barometric measurements, while "An. M." refers to the *Beagle* crew's angular (i.e. trigonometric) measurements.

Having presented the cliff-systems at five locations along the Argentinian coast down to the mouth of the Santa Cruz, Darwin then provides a detailed discussion of the stepped cliffs flanking the Rio Santa Cruz itself, along with an accompanying figure similar to the previous five (see Figure 4.9). This figure is a revision of diagrams which Darwin created while on the *Beagle*, reproduced in Figures 4.1 and 4.2. In those figures, however, Darwin was interested in differentiating each cliff from the ones next to it, and thus separated them with vertical lines; in the published presentation, Darwin instead wants to present the cliffs flanking the river in such a way that their visual similarity to the cliffs along the coast is emphasized. His ultimate goal is to argue that all these cliffs are part of a single system, produced by successive elevations; before making this argument explicitly, however, he first allows the visual similarities across illustrations to imply it.

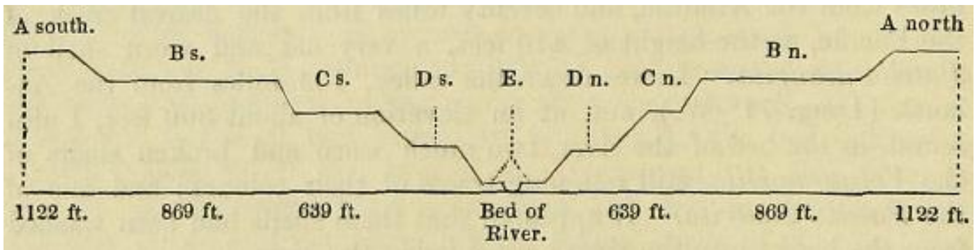


Figure 4.9: Darwin's (1846) presentation of the stepped cliffs flanking the Rio Santa Cruz (10). Cf. Figures 4.1 and 4.2.

Having presented six diagrams of terraced cliffs, Darwin begins to deal in detail with the cliffs flanking the Rio Santa Cruz. Like Darwin on board the *Beagle*, the reader has now seen that terraced cliffs are found throughout Argentina, and has begun to notice that some cliffs extend from one location to another. Darwin continues this textual voyage by presenting to readers the realization that the Santa Cruz was once a sea strait, and that it is only a river now because of successive elevations of the southern portion of the continent. Darwin's own views on the origins of the Santa Cruz were motivated by the mineralogical evidence ("white aluminous matter"), paleontological evidence (marine mussel shells dozens of miles inland from the sea and hundreds of feet above sea level), geographical evidence that the river did not used to end in the Andes (the gap in the mountains, Obstruction Sound further south), and the impossibility of the river itself having produced the cliffs flanking it.

In taking readers through this evidence, Darwin begins by describing the visual appearance of these cliffs in terms which imply their oceanic origin: "their escarpments appear like the shores of a former estuary, larger than the existing one: the escarpments, also, of the [higher] 840 feet summit-plain. . . appear like the shores of a still larger estuary" (9). Darwin also notes the gap in the Andes and the marine shells on highly raised cliffs, and presents his conclusion about the structure of the valley: "I think we must admit, that within the recent period, the course of the Santa Cruz formed a sea-strait intersecting the continent" (9-10). Darwin had originally conceived of multiple elevations early on, while looking at his Port Desire data, and later came to adapt this multiple-elevations model to the Rio Santa Cruz. In the published treatment, however, Darwin has altered the conceptual itinerary. First, he presents his views about the origins of the Santa Cruz. Only when he has done this, and only after he has prepared the ground with the visual similarities of his first six illustrations, does he begin to explicitly present his multiple-elevations view: "With respect to the three upper terraces of the S. Cruz, I think there can be no doubt, that they were modeled by the sea, when the valley was occupied by a Strait, in the same manner, (hereafter to be discussed) as the greater, step-formed, shell-strewed plains along the coast of Patagonia" (12).

Darwin has now presented a series of visuals which strongly imply a geological unity of the various cliff systems all along the Argentinian coast and up the Rio Santa Cruz. He has also suggested that the cliffs along the river look like estuaries, and has suggested that this is because they originally *were* estuaries, with the river originally being a sea-strait. He has also asserted, without yet providing reasons, that the multiple elevations which produced the Rio Santa Cruz cliffs likewise produced the coastal cliffs. Darwin is now prepared for the final move of his argument: to suggest a unified cliff-system for Patagonia resulting from multiple elevations of the entire southern portion of the South American continent.

He begins this final approach by summarizing the evidence that all of the cliffs along the coast and along the Rio Santa Cruz began under the ocean's surface: thus, marine shells were found "at heights of between a few feet and 410 feet, at intervals from latitude 33° 40' to 53° 20' South. This is a distance of 1180 geographical miles,—about equal from London to the North Cape of Sweden" (12-13). Darwin concludes that "Not only has the above specified long range of coast been elevated within the recent period, but I think it may be safely inferred from the similarity in height of the gravel-capped plains at distant points, that there has been a remarkable degree of equability in the elevatory process" (14).

Initially, Darwin's presentation of the cliff-systems has been based primarily on 1) mineralogical and paleontological evidence for an undersea origin for these cliffs and 2) visual similarities across diagrams suggesting the underlying unity of these cliffs across locations. For the final section of his argument that the Patagonian cliff-system is a unified set of phenomena, however, Darwin relies more explicitly on his numerical data, and on representations which he produced while trying to understand that data. He proceeds by taking one particular cliff-height—the 350 cliff—and presenting measurement data showing its uniformity throughout Patagonia. The extension of this "330 to 350 feet plain," Darwin writes, is "very striking, being found over a space of 500 geographical miles in a north and south line" (14). He then provides, in the form of a table, a list of seven locations which all possess a cliff of this height (see Figure 4.10). In doing this, Darwin is reworking a cross-modal perspectivization developed in May 1834, in which he tried to match similar height-measurements at the Gallegos River, the mouth of the Rio Santa Cruz, Port St. Julian, and elsewhere in an attempt to develop a list of consistent cliff-heights (CUL-DAR 34.53, reproduced in Figure 4.4). The list of places with a roughly 350-foot elevation, originally developed as prose in Darwin's notebook, is thus repurposed as a table. By changing this previous cross-modal perspectivization from a series of prose sentences to a table, Darwin shows a large number of different places, each given a line on the table, with similar measurements. He also highlights the similarity of these measurements by putting all of them in a single column, where the reader can see that every location has a measurement of between 330 and 355 feet. In this way, the prose data representation which Darwin produced during the voyage is revised into a more visually compelling table which highlights the uniformity of the numerical measurements.

	Feet.
Gallegos River to Coy Inlet (partly angular meas. and partly estim.) ..	350
South Side of Santa Cruz (ang. and barom. meas.)	355
North side of do. (ang. m.)	330
Bird Island, plain opposite to (ang. m.)	350
Port Desire, plain extending far along coast (barom. m.)..............	330
St. George's Bay, north promontory (ang. m.)......................	330
Table Land, south of New Bay (ang. m.)	350

Figure 4.10: Darwin's (1846) table of measurements and locations for "the 330 to 355 feet plain" (15). Cf. Figure 4.4.

After showing numerical data supporting the uniformity of the "330 to 350 feet plain," Darwin next presents a similar table for a plain "varying from 245 to 255 feet" which "seems to extend with much uniformity from Port Desire to the north of St. George's Bay, a distance of 170 miles" (15; see Figure 4.11). He also notes that "The extension, moreover, of the 560 to 580, and of the 80 to 100 feet, plains is remarkable, though somewhat less obvious than in the former cases" (15). Having shown the uniformity of several cliff heights across locations, Darwin concludes "I think it scarcely possible that these coincidences in height should be accidental. We must therefore conclude that the action, whatever it may have been, by which these plains have been modelled [sic] into their present forms, has been singularly uniform" (15).

	Feet.
Coy Inlet, south of (partly ang. m. and partly estim.)	200 to 300
Port Desire (barom. m.)	245 to 255
C. Blanco (ang. m.)	250
North Promontory of St. George's Bay (ang. m.)	250
South of New Bay (ang. m.)	200 to 220
North of S. Josef (estim.)	200 to 300
Plain of Rio Negro (ang. m.)	200 to 220
Babia Blanca (estim.)	200 to 300

Figure 4.11: Darwin's (1846) table of measurements and locations for the plain "varying from 245 to 255 feet" (15). Cf. Figure 4.4.

At the outset of this chapter, Darwin promised "to show the remarkable equability of the recent elevatory movements," a seemingly rather modest goal (6). By the end of this chapter, however, Darwin has shown, not just this "equability," but that these elevator movements have produced a continent-wide system of remarkably uniform stepped cliffs and have also turned a former sea-strait into a river. At the end of this chapter, Darwin finally provides readers with the "Summary of Results" which he hopes they will draw from his analysis:

> It may be concluded that the coast on this [eastern] side the continent, for a space of at least 1,180 miles, has been elevated to a height. . . of 400 feet in Southern

> Patagonia. . . ., [and] that there have been at least eight periods of denudation. . . .; and finally, that, anterior to the elevation attested by these upraised shells, the land was divided by a Strait where the river Santa Cruz now flows, and that further southward there were other sea-straits, since closed. (18-19)

Employing data representations derived from his inventional processes in April and May 1834—schematic cross-sections and measurements of the cliffs flanking the Rio Santa Cruz, lists of locales with cliff-heights of 330-350 feet, and so on—Darwin has made his case for a continent-wide system of eight or more elevations which has produced a continent-wide cliff system, the odd mineralogical and paleontological features found throughout Patagonia, and the broad, terraced cliffs along the banks of the Rio Santa Cruz.

Conclusion

Darwin began his *Beagle* survey of Southern Patagonia with observations of stepped cliffs at Port Desire and a Lyellian reasoning strategy that seemed promising: when faced with a geological phenomenon typically found under the sea that is instead above sea level, try to determine whether it can be accounted for by assuming that the phenomenon originally occurred underwater and was subsequently raised by the gradual elevation of the land. During his subsequent travel down the Argentinian coast, Darwin extended Lyell's reasoning strategy in two ways: first, he assumed that the series of cliffs, with their misplaced marine shells, resulted from a series of elevations, rather than just one; and second, he assumed that these elevations were not limited to one location, as at the Temple of Serapis or at St. Jago, but rather extended throughout Argentina. Travelling up the Rio Santa Cruz, Darwin used this double extension of

Lyell's gradualistic reasoning strategy to explain the cliffs flanking the river—cliffs which could not possibly have been caused by the river itself. As the *Beagle* sailed on to Port Famine in Tierro del Fuego, Darwin thus had a chaotic and complicated mass of cliff-elevation data and a Lyllian multiple-elevations account of the history of Patagonia.

Along the Santa Cruz and on the way to Port Famine, Darwin produced cross-modal perspectivizations of some of his measurement data: diagrams of the different elevations of the river cliffs, locations which all had a 330-350-foot plain, and so on. These perspectivizations helped Darwin to take numerous measurements of temperature and air pressure at different places and bring them together into a single data representation, thereby making it easier for Darwin to perceive patterns in his data which could be plausibly related to his multiple-elevations account. In short, Darwin's mathematical invention aided him in justifying his dual expansion of Lyell's reasoning strategy, applying it to new phenomena and at a larger scope than Lyell did. This mathematical invention culminated in lists of cliff-heights which Darwin saw as revealing the underlying structure of the Argentinian cliff-system.

But Darwin's invention was not just a task of simplifying and re-representing his numerical data and then looking for patterns. Darwin also had to address the fact that locations did not all have cliffs of the same height, and that particular cliffs were not found at every location. In short, only some of Darwin's numerical data fit his model. The data that didn't fit had to be plausibly accounted for. Darwin had to refer to memories of the visual appearance of cliffs in various locations, reason analogically from well-understood variations in height and one location to less clear-cut variations in height at another, and so on in order to tame his recalcitrant data. It was not enough, then, for Darwin to fit patterns in his measurements to his

Lyellian model; he also had to plausibly account for measurements which seemed to disconfirm that model.

In presenting this cliff-system to a scientific audience in 1846, Darwin takes them along a conceptual voyage somewhat similar to his own. After first showing the visual similarity of terraced cliffs at five locations along the coast, as well as along the Rio Santa Cruz, Darwin then takes lists of locations each having a particular cliff elevation from his notebook, recasting them as visually compelling tables. In presenting this account to his readers, Darwin adapted cross-modal perspectivizations created in his notebooks to persuasive uses, so that they made intuitively compelling to readers the same ideas that they had first made intuitively compelling to Darwin himself. Darwin's mathematical invention, then, involved 1) distilling chaotic mathematical data into more orderly and explanatorily useful patterns of data; 2) Using these patterns to develop novel insights about nature; 3) plausibly accounting for data-points deviating from these patterns and insights; 4) re-representing these data patterns as cleaner, simpler cross-modal perspectivizations; and 5) adapting these perspectivizations into parts of visual-verbal argumentation presenting Darwin's model persuasively to scientific audiences. Insofar as Darwin's case is representative, then, even in its humblest aspects—the day-to-day processing of numerical data to reveal robust patterns—mathematics in science is irreducibly inventional and rhetorical, both with regard to theory and supporting argumentation.

Chapter Five: Conclusion

Daniel Dickson-LaPrade

In the foregoing chapters, we have traced three episodes of Charles Darwin's multimodal scientific invention. In all three episodes, we see the same kind of inventional dynamic. In pursuit of novel insights about nature, Darwin iteratively represents and re-represents his knowledge in various ways. Some of these knowledge representations involve the gathering together of previously disparate knowledge in a new modality—that is, some of these knowledge representations are cross-modal perspectivizations. Darwin uses these perspectivizations to develop new insights about nature, which he is able to revise into plausible scientific models or explanations. Having developed such insights, Darwin then returns to cross-modal perspectivizations created previously. He revises these prior perspectivizations in various ways, thereby turning them into parts of a multimodal argument by which he presents his theoretical innovation plausibly to a scientific audience. In short, Darwin constructs knowledge representations during the course of his investigation which may be revised and repurposed for published argumentation. In this way, the processes of developing theoretical innovation gradually gives way to the process of generating argumentation for presenting that innovation, with some of the same knowledge-representations appearing throughout.

But in addition to providing both theoretical innovation and potential rhetorical tactics, Darwin's cross-modal perspectivizations also, with time, come to provide Darwin with large-scale rhetorical strategies which structure large portions of text. In revising his notebook list of phenomena which are similar to budding in plants, for instance, Darwin reorders the list in such a way that it has a direction: elements early in the list involve the construction of an organism's entire body, while elements late in the list involve only the healing of simple injuries and everyday growth. By doing this, Darwin takes what seem to be entirely distinct natural phenomena—sexual reproduction, regeneration of limbs, ordinary growth—and turns them into a continuum of items, each of which is separated from its neighbors by only a small difference. This change of distinct phenomena into a continuum strengthens the possibility that all these phenomena share a similar nature. Further, the sheer variety and number of items in the directional list impresses the reader with the potential explanatory power of his pangenesis theory. Thus, a list which began as a way to better understand budding in plants, a list with no direction or argumentative significance, becomes a way to alter the reader's conception of natural phenomena, and also provides an epideictic expression of how impressive Darwin's pangenesis theory might be. So useful are these rhetorical functions that the revised list influences the structure of Darwin's entire presentation of his pangenesis theory. It is only after spending several pages describing connections among adjacent items on the list that Darwin presents the list itself. The list thus serves as a sort of destination for Darwin's argument. What began as a purely investigative list is thus revised into a more rhetorically complex perspectivization, with this revision suggesting to Darwin a coherent, overall approach for presenting his pangenesis theory to readers. Theoretical insight gives way to rhetorical tactic, which gives way to overarching rhetorical strategy—with the list providing inventional continuity throughout the process.

In developing his new genre of evolutionary tree diagrams, Darwin's revision becomes even more important to the overall rhetorical strategy of his finished publication. Between his notebook diagrams of 1837 and his final publication in 1859, Darwin has added visual conventions from geometry diagrams and has added more regimentation to the time dimension. These revisions allow for a wider variety of visual-verbal arguments to be grounded in the diagram. In the process of developing the final form of his tree diagram, and of finding ways to make his evolutionary account intuitively appealing to readers, Darwin thus comes to develop an overarching rhetorical strategy: use the same diagram to show how the basic concepts of branching evolution, natural selection, and extinction can explain the formation of new species, the formation of larger taxa, and observed facts about taxonomy and paleontology. The tree diagram published in 1859, then, far from being a single knowledge-representation of the sort produced by Darwin in his notebooks, becomes the anchor for a coherent, overarching rhetorical strategy in which several visual-verbal arguments can all be equally well grounded in a single, straightforward illustration. Again, a knowledge representation which begins as a means of developing theoretical insight is revised over time to become a rhetorical structure itself; as this rhetorical structure evolves, it suggests to Darwin a comprehensive rhetorical strategy.

Darwin's mathematical invention likewise provides more than just a piece of multimodal argumentation. In developing lists of locations with similar cliff-heights in his notebooks, Darwin is impressed by the large number of locations which share certain of these heights. By revising two of these height-lists as two-column tables, Darwin foregrounds for his reader 1) the large number of locations sharing a similar cliff-height and 2) the near-identity of this cliff-height even at locations quite far apart. But it is only toward the end of his multimodal argument that Darwin presents these two cliff-height tables. First, he indirectly argues for the similarity of cliffs across locations by using the same visual conventions to display these cliffs in his first six illustrations. The two tables thus serve as the climax or conclusion to his chapter. Thus, when Darwin generates a particularly effective knowledge representation that will work for presenting theory to an audience, he doesn't just gain a piece of multimodal argument: he also gains a way of thinking about the overall rhetorical strategy which he will use in presenting his theoretical innovation. Whether the revised cross-modal perspectivization serves as the climax of the argument or as a sort of hub which anchors several pieces of multi-modal argumentation, the latter stages of Darwin's invention produce rhetorical strategy as well as theoretical innovation and persuasive knowledge representation. The iterative representation and re-representation of knowledge which yields cross-modal perspectivizations and novel theoretical insights additionally produces, with time and revision, particular rhetorical tactics, and ultimately large-scale argumentational strategies which structure large portions of text.

The analysis in the foregoing chapters has been limited to particular episodes of Darwin's own inventional practice. However, even the limited scope of this analysis shows that Darwin's invention is importantly related to inventional work by previous naturalists, and generates materials useful for inventional work by later naturalists. In generating his pangenesis theory, for example, Darwin is indebted to Herschel's reasoning strategy of list-making, originally derived from Francis Bacon. Similarly, Darwin's multiple-elevations model of how Argentina's stepped cliffs originated is indebted to Lyell's reasoning strategy of considering how an elevation of land might yield observed geological phenomena. Darwin also generated reasoning strategy himself which could be used by later naturalists. The strategy of assuming a now-extinct common ancestor to clarify relationships among existing organisms has been useful to mid-twentieth-century scientists working to understand the shared traits of living and extinct ants and wasps. Further, the visual conventions of various tree-diagrams used by evolutionary scientists even today have a clear lineage going back to Darwin's representational practices in his tree diagram in *On the Origin of Species*. The reasoning strategies and visual conventions already available to

Darwin, then, serve as inventional materials; furthermore, Darwin generates new reasoning strategies and new representational practices in the process of producing scientific argumentation. Insofar as later naturalists take up Darwin's representational practices, they become visual conventions; insofar as later naturalists take up Darwin's reasoning strategies, we may say that they become special topoi. Thus, the materials with which a scientist works in generating theoretical innovation are not limited to progressively more incisive or broad claims about nature; they also include special topoi and representational conventions which can be borrowed and adapted to suit new investigative (and rhetorical) purposes. Thus, just as Darwin's invention shows us a continuity between theoretical innovation, the development of bits of multimodal argumentation, and the development of overall rhetorical strategy, it also shows us that assertions about nature, methods for presenting knowledge about nature, and practices for deriving novel claims about nature must be understood together in scientific invention. Just as there is a continuity of process between theoretical innovation and rhetorical invention, so too there are no clear demarcations separation propositional claims about nature, representational practices for depicting nature, and topoi which allow for the generation of new inferences about nature. Assertion, conception, representation, and expression all work together in Darwin's inventional practice.

There are, of course, limitations to the foregoing study. For example, many modalities are left untouched in the preceding chapters. Modern modalities, such as three-dimensional, computer-aided data visualizations, are of course not addressed; neither are thought experiments. Moreover, most scientific knowledge in the past century has been made, not by individual scientists scribbling in notebooks, but by teams of scientists working in unison on specialized and highly technical problems within a particular research tradition. It may be useful to examine these other modalities, and also to examine how scientific invention differs when it is the result of collective inquiry rather than individual investigative work. For example, ethnographic observation of scientific laboratories by Heather Brodie Graves, Bruno Latour, Steve Woolgar, and others could be profitably combined with the method for analyzing invention employed in this study. Scholars could record how movement between talk, written notes, email, digital photographs, computerized data models, and so on generate inferences about nature, representational practices, and reasoning strategies during the course of a particular laboratory investigation. By tracing such a collaborative and multimodal inventional process from earliest observation and experiment to published article, much could be learned about how shifts among modalities generate shareable conceptual resources in the lab.

The use of cross-modal perspectivization to analyze scientific invention might also have useful pedagogical implications for scientists in training. How do graduate students in STEM disciplines, for example, become socialized not just in the claims about nature, but in the representational practices and reasoning strategies in common use within their discipline? How do they practice the use of these representational practices and topoi? Are there important differences between the ways that experts and novices employ these inventional resources?

Neither scientific inquiry, nor scientific creativity, nor scientific argumentation can be simple or algorithmic. I believe, however, that the approach to scientific invention employed in this project might be useful in finding new ways for scholars of rhetoric to relate epistemology, scientific communication practices, and the generation of theoretical innovation in science. It may also provide pedagogically useful knowledge about how scientists in training develop facility with the special topoi and cross-modal perspectivizations available within their disciplines.

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