EVOLUTION IN THE LIGHT OF TIME:
CONCEPTULIZING THE EXTENDED EVOLUTIONARY SYNTHESIS

by

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ABSTRACT

Compelled by converging research in the natural sciences suggesting the stratigraphic nature of time, I argue for a temporal approach to the venerable problem of *synthesis* in evolutionary theory. Geneticist and pioneer of the Modern Synthesis (MS), Theodosius Dobzhansky (1900-1975), constructed one of the most powerful *synthesis arguments* in the history of evolutionary biology in the classic "Nothing in Biology Makes Sense Except in the Light of Evolution" (1973). I argue that *nothing in evolution makes sense except in the light of time*, such that the problem of evolutionary time plays a powerful role in making sense of the conceptual architecture of the Extended Evolutionary Synthesis (EES). The EES offers a strong alternative to the temporal and causal idealizations operating at the hardened core of the MS. I create the philosophical concept of *stratigraphic time* to strengthen connections between the four problem agendas or "causal catchalls" structuring the new synthesis: (1) *developmental plasticity*, (2) *developmental bias*, (3) *inclusive inheritance*, and (4) *niche construction* (Laland 2015 et al.). The dissertation is driven by two critical arguments (Chapters 1-3) concerning the subordination of time to process, and two constructive arguments (Chapters 4 and 5) concerning the nature of evolutionary time, which together attest to the conceptual strength of a temporal approach to the multiplicity of evolutionary problems pursued by the EES, and especially the connections between them.

Chapter 1, "Embracing the Problematic Structure of the Extended Evolutionary Synthesis," explicates and evaluates the core assumptions of the EES in contrast with those of the MS, which has served as the dominant conceptual framework for evolutionary science and theory since the early twentieth century. Chapter 2, "Deep Time: The Forgotten Frontier," critically argues that evolutionary time has been subordinated to evolutionary process, that the problem of evolutionary

time must be revived after its eclipse at the origin of evolutionary theory, especially due to Darwin's unnecessarily strict commitments to gradualism, adaptationism, and to the preeminence of natural selection. Chapter 3, "The Chronometric Subordination of Time to Movement in Philosophy, Science, and Society,," critically argues that the subordination of evolutionary time to process is primed by the chronometrically facilitated subordination of time to movement, what mathematician, physicist, and philosopher of science Henri Poincaré (1854-1912) called an *unconscious opportunism* in philosophical and scientific thought. The constructive arguments unfolded in Chapter 4, "The Continuous Variation of Evolutionary Contingency," and Chapter 5, "Stratigraphic Time: The Synthesis of Deep and Developmental Rhythms," attempt to respect causal thinking while conceptualizing evolutionary processes not according to causal laws but rather according to passive and active temporal syntheses (or modes of repetition), effectively delimiting causal thinking to a provisional conceptualization. Stratigraphic time enables conceptualization of the multiplicity of evolutionary process, driven by a new concept of *evolutionary contingency*. I argue that the roles of chance and causation in the EES are strengthened by concepts of difference and repetition, akin to the conceptual roles played by arrows and cycles of time in the formation of geological and evolutionary thought. These critical and constructive arguments are guided by Gilles Deleuze's philosophy of time, which he conceptualizes under the rubric of *repetition*. The three passive and active temporal syntheses, or modes of repetition, Deleuze creates to think the nature of repetition provide conceptual tools for evolutionary synthesis through stratigraphic time.

INTRODUCTION: EVOLUTION IN THE LIGHT OF STRATIGRAPHIC TIME

Compelled by corroborating research in the natural sciences suggesting the stratigraphic nature of time, I argue for a temporal approach to the venerable problem of *synthesis* in evolutionary theory. Geneticist and pioneer of the Modern Synthesis (MS), Theodosius Dobzhansky (1900-1975), constructed one of the most powerful *synthesis arguments* in the history of evolutionary biology in the classic "Nothing in Biology Makes Sense Except in the Light of Evolution" (1973). I argue that *nothing in evolution makes sense except in the light of time*, such that the problem of evolutionary time plays a powerful role in making sense of the conceptual architecture of the Extended Evolutionary Synthesis (EES). The extended synthesis offers a strong alternative to the temporal and causal idealizations operating at the hardened core of the MS. The EES has roots in earlier alternative conceptualizations of evolutionary temporality and causality (Simpson 1944, Gould 1985, Beatty 1986), but these referenced percolations of extensions to the MS has taken formidable shape since the turn of the century (Pigliucci 2007, Laland et al. 2009, Callebaut 2010). In this dissertation, I problematize concepts of evolutionary temporality and evolutionary causality explicitly and tacitly operative in evolutionary syntheses. I create the philosophical concept of *stratigraphic time* to strengthen connections between the four problem agendas or "causal catchalls" structuring the EES: (1) *developmental plasticity*, (2) *developmental bias*, (3) *inclusive inheritance*, and (4) *niche construction* (Laland 2015 et al.). These previously neglected conceptual and empirical exigencies challenge tacit idealizations in evolutionary thought maintaining that evolutionary time unfolds only gradually and preeminently determined in direction by natural selection. The dissertation is driven by two critical arguments (Chapters 1-3) concerning the subordination of time to process, and two constructive arguments (Chapters 4 and

5) concerning the nature of evolutionary time, which together attest to the conceptual strength of a temporal approach to the multiplicity of evolutionary problems pursued by the EES, and especially the connections between them.

Chapter 1, "Embracing the Problematic Structure of the Extended Evolutionary Synthesis," explicates and evaluates the core assumptions of the EES in contrast with the MS, which has served as the dominant conceptual framework for evolutionary science and theory since the early twentieth century, combining previously disparate strands of (1) Darwinian evolution via natural selection, (2) models and concepts from population genetics, as well as (3) Mendelian models of inheritance (Huxley 1942, Mayr and Provine 1988). Evolutionary thought has been forced to encounter empirical discrepancies and resultant theoretic tensions between the MS and the problem agendas pursued by a multiplicity of earth and life sciences, which ostensibly evince nontrivial causalities and contingencies key to understanding the multiplicity of the modes and tempos of evolutionary processes. I explicate and critically evaluate the tacit idealizations of evolutionary temporality and causality central to the structure and content of classic and contemporary evolutionary syntheses with the aim of newly conceptualizing problems pursued by adjacent theoretical traditions and research programs, which contribute to the new, revised, and expanded synthesis: evolutionary-developmental biology (Müller 2017), the study of phenotypic plasticity (Pigliucci 2004), niche construction (Odling-Smee, Laland, and Feldman 2003), the geometry, physics, and philosophy of biological time (Winfree 2001), punctuated equilibrium (Eldredge and Gould 1993), genomics (Griffiths and Stoltz 2013), cell biology (Rose 2003), embryology (Robert 2004), epigenetics (Jablonka and Lamb 2008), technical evolution (Leroi-Gourhan 1993), cultural evolution (Boyd and Richerson 2005), philosophy of nature (Godfrey-Smith 2009), theoretical biology (Varela and Stein 1994), and so on. The multiple methodological techniques, conceptual architectures, inferential strategies, and underlying assumptions unique to each evolutionary discipline creates the venerable problem of *synthesis*. Philosophy of nature is specially suited to the task of conceptually synthesizing the evolutionary and developmental modes and tempos of organisms and their lineages. Geology, paleontology, and biology have played key roles in the construction and transformation of evolutionary theory. The disciplines have all too disparately cultivated these roles, however, giving rise to conflicting assumptions within the theory. Competing attempts to synthesize the respective disciplinary contributions have achieved only modest success. The avowedly problematic structure of the new synthesis embraces the previously neglected empirical exigencies pursued by the connected disciplines, embracing explanatory perplexity in relation to the nature of the processes involved. While the core EES concepts of *reciprocal causality* and *constructive development* free causal multiplicity and ontogeny from unidirectional causality and phylogeny, the EES still subordinates evolutionary time to causal movement. The causal multiplicity and reciprocity admit of variable evolutionary rates of stability and modification, but those rates subordinate time itself to process.

Chapter 2, "Deep Time: The Forgotten Frontier," critically argues that evolutionary time has been subordinated to evolutionary process, that the problem of evolutionary time must be revived after its eclipse at the origin of evolutionary theory, especially due to Darwin's unnecessarily strict commitments to gradualism, adaptationism, and to the preeminence of natural selection. Chapter 2 sets the stage for the problem of evolutionary time by reconstructing how the geological discovery of deep time enabled the theory of evolutionary history, but which became eclipsed by the gradualist assumption of Darwinian theory. The rational quest of geology to reconcile the arrows and cycles of time is marked by increasingly rigorous and systematic solutions to the problem of deep time (Gould 1987, McPhee 1980, Lyell 1830). The rationalist reconciliations increasingly eclipse the depth of the problem of geological time through circumscriptions its multiplicity and insensibility in a hierarchy of causal relations. The growth of methodological rigor and inferential rationality in geology fostered the development of evolutionary theory. It is at the origin of evolutionary theory that the quest to render deep time rational culminates in the gradualist solution, an offspring of the deep time problem, not to mention a necessary condition for the preeminent operation of a rational mechanism of modification (natural selection). The explication of the problem of time in the history of philosophy and physics illuminates the problem of time in geology, evolutionary biology, paleontology, and so on, by thinking through time's various subordinations to movement and measurement.

Chapter 3, "The Chronometric Subordination of Time to Movement in Philosophy, Science, and Society" critically argues that the subordination of evolutionary time to process is primed by the chronometrically facilitated subordination of time to movement, what mathematician, physicist, and philosopher of science Henri Poincaré (1854-1912) called an unconscious opportunism in philosophical and scientific thought. The genetically determined assumption of unidirectional causality in consensus syntheses of the past exemplifies these subordinations. Explication of the uncritical subordination of time to movement operative in philosophy and science enables evaluation of the problem of evolutionary time in its various subordinations to evolutionary process. Poincaré's problematization of the subordination, at least the reciprocal determination, of temporality to causality opens a philosophical door to a new conceptualization of their relations, beyond the seemingly inevitable supposition that time is reducible to causal succession—moving from ostensive antecedent to ostensive consequent. The question begged (petitio principii) by the problem, as acknowledged by Poincaré in the last sentence, is constructively engaged in the final two chapters, which attempt to respect causal thinking while conceptualizing evolutionary processes not according to causal laws but rather according to passive and active temporal syntheses (or modes of repetition), effectively delimiting causal thinking to a provisional conceptualization. The powerfully persistent perception of cause-effect relations ineluctably influences thought, and should be respected as such. The derivative status of time as defined in Aristotle's *Physics* is gradually reconfigured throughout the history of Western philosophical thought, from the Stoics through Neoplatonism into the Middle Ages, Descartes, Newton, and Leibniz, but takes a revolutionary turn in Kant's critical philosophy. After Kant's inversion of priority in the relation between time and movement, the tendency to chronologically order time is upset by contingently aberrant movements, movements of the ordinary, the advent of which are non-chronological. The inversion of priority demands new approaches to problems of time. Philosophy is pressured to create and connect and extend concepts *within* time, through processes of becoming, instead of assuming or appealing to previously existing forms *outside* of time. "The aim of philosophy," after the Copernican turn in temporality, writes Daniel W. Smith, "will no longer be to discover pre-existent truths outside of time, but to create non-pre-existing concepts within time" (Smith 2013, 381, Deleuze 2013). "Deleuze introduces time into the form of concepts. Concepts are not eternal and timeless (true in all times and all places), but are created, invented, produced in response to shifting problematics. In a sense, Deleuze is incorporating into philosophy the transformation that occurred in geology with the discovery of 'deep time'" (Smith 2020, 36). The creation of the concept of stratigraphic time in the dissertation aims for consistency with Deleuze's temporal vision of philosophy.

The constructive arguments unfolded in **Chapter 4**, "The Continuous Variation of Evolutionary Contingency," and **Chapter 5**, "The Temporal Synthesis of Biological and Evolutionary Rhythms," attempt to respect causal thinking while conceptualizing evolutionary processes not according to causal laws but rather according to passive and active temporal syntheses (or modes of repetition), effectively delimiting causal thinking to a provisional conceptualization. The problematic structure of the EES accommodates the problematic nature of evolutionary time by affirming a variety of deep and developmental tempos, and affirming differential rates as nontrivial sources of direction and pattern in evolutionary history. Understanding the problematic nature of time is necessary for connecting the deep and developmental scales of change, for time is the form of change as such, it is continuous variation. The evolutionary modes of change central to the EES only make sense in the light of time as continuous variation. The concept of stratigraphic time enables understanding of the problematic nature of time as such and how the manifold modes of time contribute to evolutionary patterns observed and processes inferred. Stratigraphic time enables conceptualization of the multiplicity of evolutionary process, driven by a new concept of evolutionary contingency. Catalyzed by contemporary discussions of the problem of contingency in evolutionary thought, I argue that the roles of chance and causation in the EES are strengthened by concepts of difference and repetition, akin to the conceptual roles played by arrows and cycles of time in the formation of geological and evolutionary thought. These critical and constructive arguments are guided by Gilles Deleuze's philosophy of time, which he conceptualizes under the rubric of *repetition.*

Deleuze's *Difference and Repetition* (1968) conceptualizes time under the rubric of repetition, as non-metric and non-chronological manifold of passive and active syntheses. Deleuze's syntheses of time are forms of repetition, and their transcendental role in Deleuze's philosophy of time provide a defense of "Repetition for Itself"—the title of the second chapter of the work—whereby the paradox of the sameness and difference of any given repetition is explicated in terms of time, serving as a formal case of the paradox. The three types of passive syntheses are as follows: (1) habit, which 'prioritizes' the present, what Deleuze calls the *living present*, as contraction of the past; (2) memory, which prioritizes the past as the pure fullness of any given present, in a bifurcating relation of coexistence with the present, enabling it to pass (or flow); and (3) the new, which prioritizes the future, and refers to the productive processes of temporality. The irreducible modalities of metamorphosis are asymmetrical temporal syntheses coexistent upon a plane of continuous variation. The temporal syntheses do not work on continuous variation itself but rather on the variations actualized through the modes and tempos of continuous variation. The difference in kind between time and the temporal multiplicity of various disciplinary strata is a problematic intrinsic to the construction of stratigraphic time.

The dissertation problematizes the causal assumptions and inferences operative in evolutionary theory, specifically the unidirectional causality of the MS and the reciprocal causality of the EES. Chapter 4 first problematizes the causal assumptions and inferences operative in evolutionary theory, specifically the unidirectional causality of the MS, but also the reciprocal causality of the EES. The subordination of time to movement explicated in the third chapter becomes evident as the subordination of evolutionary time to causal movement in the fourth chapter. While the concepts of reciprocal causality and constructive development free causal multiplicity and ontogeny from unidirectional causality and phylogeny, the EES still subordinates evolutionary time to causal movement. The causal multiplicity and reciprocity admit of variable evolutionary rates of stability and modification, but those rates subordinate time itself to their processes, change as such to actual changes. While the concepts of reciprocal causality and constructive development free causal multiplicity and ontogeny from unidirectional causality and phylogenetic determinism, the EES still subordinates evolutionary time to causal movement. The chronometric subordination of time to movement explicated in Chapter 3 becomes evident as the subordination of evolutionary time to causal movement, in Chapter 4. The problematization of the causal assumptions and inferences of the MS and the EES exposes the unconscious opportunism of subordinating evolutionary time to causal movement. In the MS the subordination occurs by way of the subordination of causal multiplicity between evolutionary and developmental processes to unidirectional causation from genetic programming to phenotypic expression, and by way of the subordination of variation to selection. The unconscious opportunism is deeply sedimented in the

MS. While the core EES concepts of *reciprocal causality* and *constructive development* free causal multiplicity and ontogeny from strictly unidirectional causality and phylogenetic determinism, the EES still subordinates evolutionary time to causal movement. The causal multiplicity and reciprocity admit of variable evolutionary rates of stability and modification, but those rates subordinate time itself to the fluctuations of processes. Freed from causal movement, evolutionary time becomes an independent and autonomous multiplicity. The concept of *evolutionary contingency* assembles the roles of *chance* and *causality* in the determination of the modes and tempos of time itself in Chapter 4 (Gould 2002, Plotnitsky 2004). The problematic thread of the dissertation affirms the innovative steps taken by the EES through causal thinking while affirming the deeper and ultimately more pragmatic ways of conceptualizing evolutionary processes—ways more consistent with the problematic structure of the EES. The stratigraphic temporality of evolutionary contingency actualizes the evolutionary-developmental history chronicled and archived by salient sciences in Chapter 5.

Biology in the Light of Evolution

> *Seen in the light of evolution, biology is, perhaps, intellectually the most satisfying and inspiring science. Without that light it becomes a pile of sundry facts—some of them interesting or curious but making no meaningful picture as a whole.*

> Theodosius Dobzhansky, "Nothing in Evolution Makes Sense Except in the Light of Evolution" (1973, 129)

The field biology, experimental work, and conceptual innovations of *Drosophila* experimenter and beetle taxonomy specialist Theodosius Dobzhansky played formative roles in producing the Modern Synthesis. The title of Dobzhansky's magnum opus, *Genetics and the Origin of Species*

(1937), clearly indicates an attempt to unify genetic disciplines following in the wake of Mendelian inheritance, which had become increasingly enthusiastic about the gene as the central explainer in evolutionary theory, and Darwinian thinking, which maintained that organisms (involving genes) are the primary targets of evolutionary explanations. Dobzhansky's work struggled with the theoretical and practical problems of synthesizing the Mendelian experimental institutions with the study of natural history—problems persisting today. The work's impressive impact became evident decades after its publication at events dedicated to determining the evolutionary synthesis, as reported by Stephen Jay Gould, who was in attendance at the groundbreaking conference called *Workshop on the Evolutionary Synthesis* (1974): "Speaker after speaker arose to state that his own contribution had been produced by reading Dobzhansky's account first" (Gould 2002, 519). Dobzhansky could have never imagined facilitating what Gould calls "the hardening" of the MS (Ibid., 520). The received history of the passage from Dobzhansky's influential essay exemplifies the hardening of the synthesis through adaptationism and gene-centrism, idealizing currents of evolutionary theory the present chapter argues grate against the grain of Dobzhansky's thought.

Dobzhansky's dictum is perhaps the most quoted statement in evolutionary biology and philosophy of biology, though most allusions to the dictum demonstrate little engagement with the whole article dedicated to the claim that "Nothing in Biology Makes Sense except in the Light of Evolution," in which the sense of Dobzhansky's claim is given context and variously rearticulated. References to Dobzhansky's famous dictum often transform it for the sake of encountering new problems, and in other cases emphasize a certain approach to the dictum. For example, Steven Rose's version in *The Chemistry of Life* aims to broaden the adage (1999, 370): "Nothing in biology makes sense, said the great evolutionary biologist, Theodosius Dobzhansky, except in the light of evolution. My version of this statement is broader: nothing in biology makes sense except in the light of history." Explanatory relationships between macromolecules, cells, organisms, groups, etc., are construed according to biological principles pressured by Rose to integrate "an understanding of historicity, for…biological systems have to be understood in temporal as well as molecular terms if their development and evolution are to become meaningful" (Ibid.). Rose casts a spotlight on the assumption beating at the heart of Dobzhansky's dictum, namely that the grand diversity of lifeways observed of earth makes sense only if they share common ancestral history—metaphorically expressed, though often idealized, *tree of life*. Akin to the distribution of anatomical, embryological, and biogeographical characters observed by Darwin, the newer observations of the distribution of molecular characters available to Dobzhansky, and with higher resolution by Rose, only make sense if the contemporary genomes sequenced and studied share common ancestry. This dissertation takes a conceptual step beyond Rose's emphasize on historicity, on the temporal nature of development and evolution. While "nothing in biology makes sense except in the light of evolution" (Dobzhansky 1973), such that evolutionary processes shed light on biological causalities and contingencies. I argue that *nothing in evolution makes sense except in the light of time*, such that the problem of evolutionary time plays a powerful role in making sense of the conceptual architecture of the EES.

While Rose's reading is nuanced and contextualized the frequently heeded dictum has been variously idealized and uncritically adapted for purposes in conflict with the sense Dobzhansky intended. A common idealization overdetermines adaptation: 'nothing in biology makes sense except in the light of adaptation.' According to a common methodological assumption concerning historical inferences about evolutionary processes and patterns, the central explanatory targets are adaptations. Adaptive traits are most evident in contemporary organisms and their assemblages—echoing the geological principle analyzed in Chapter 1 that "the present is the key to the past" (Lyell 1830). The core of the adaptationist approach to evolutionary, and in turn biological, problems are the *selective histories* of the adaptive traits of organisms under investigation. The *backward-looking* adaptationist approach of the MS, which aims to determine selective histories (the past) through the lens of currently functioning adaptive traits (the present), suffers from two idealizations critiqued by Gilles Deleuze: (1) *preformism* and (2) *actualism* (Deleuze 1994). Paul Griffiths' sustained and highly detailed meditation on the effective history of the dictum and its philosophical implications argues that "an evolutionary perspective is indeed necessary, but that it must be a forward-looking perspective informed by a general understanding of the evolutionary process, not a backward-looking perspective informed by the specific evolutionary histories of species being studied" (Griffiths 2006, 11). The evolutionary definition the backwards-looking perspective gives of *biological functioning* whereas the forward-looking perspective

Evolutionary biology is often tacitly parsed into a couple of collections of central assumptions, those involving *the fact of evolution* versus those involving *the mechanism of evolution*. The very fact of evolution implies the shared history of life on earth, and its arborescent representation, the "tree of life." The arboreal metaphor precedes Darwin, but the latter ascribes newly historical and genealogical directionality to the tree, and he speculated that perhaps evolution forms an assemblage of multiple trees rather than just one (Godfrey-Smith 2014, 8). The other central collection preeminently concerns natural selection. While affirmation of the fact of evolution Dobzhansky deemed beyond doubt, the nature of natural selection in relation to other proposed mechanisms of change is open to debate: "Evolution as a process that has always gone on in the history of the earth can be doubted only by those who are ignorant of the evidence or are resistant to evidence, owing to emotional blocks or to plain bigotry. By contrast, the mechanisms that bring evolution about certainly need study and clarification" (Dobzhansky 1973, 129).

Dobzhansky also assumes a gradual rate of evolution, without problematizing evolutionary time. The incremental operation of natural selection determines the evolutionary arrow of time (through idealization in the sense of Godfrey-Smith 2009, 2014), though not necessarily in a progressive direction. Incremental evolutionary change is a necessary condition for 'progressive vectors' but not a sufficient condition, however one might define *progress.* The zealous search for progressive arrows of evolutionary change is frequently in evidence throughout the history of evolutionary philosophy and science. The penchant for progress persists despite scant empirical support for the prediction or retrodiction of progressive evolutionary change—as paleontologists, and Darwin himself, have come to realize. The present effort persistently applies pressure to assumptions and avowals of progressive evolution, which it takes to be a common misconception about Darwinian "descent with modification"—Darwin's preferred description of his explanatory target. Darwin often resisted the term *evolution* due to the naïve ascription of progressive directionality to the contingent historical process, due to the confusion that the gradual modification of descent automatically entails an arrow of improvement, an optimism unwarranted by Darwin's work and the evolutionary research accumulating in its wake.

The common misconstrual of Dobzhansky's dictum whereby *nothing in evolution makes sense except in the light of adaptation* is centered in the claim that "the structure of living organisms only makes sense when viewed as a set of evolutionary adaptations to specific selection pressures" (Griffiths 2006, 13). A prominent philosopher of biology, Michael Ruse, for instance, conceptualizes *the fact of evolution* in terms of evolution with focal reference to adaptations as *end* products: "organisms are the end products of evolution and…the major mechanism of evolution is Darwinian natural selection" (Ruse 2009, 249). Ruse's definition of evolutionary change is restricted to "the direction of adaptive efficiency," under the control of purpose-driven mechanisms. Adaptations are the defining features of organisms, the reasons for their existence. Hands, eyes, brains, and many other organs have been selected to enable reproductive success. These adaptations are the keys to understanding evolution. Chapter 5 rethinks the nature of adaptation through the concept of stratigraphic time.

Evolution in the Light of Time

Arguably the most ubiquitous adaptations on earth involve time. Circadian rhythms are not the only modes of biological timing characteristic of organisms, but evidently the most repetitious and most observable on earth. A pioneer in the biophysics of time, Arthur Winfree (1942-2002), attests to their ubiquity: "One doesn't have to look at many living organisms before noticing that a lot of behavioral physiology is temporally organized in periodic patterns. In fact, if I had to decide what impresses me as the single most conspicuous feature of natural ecosystems, I would say that it is the daily and seasonal periodism and the consequent temporal organization of niche structure, food webs, and behavior" (Winfree 2001, 545). Time has become problematized by work in the earth and life sciences, and in areas of physics and chemistry, rendering longstanding metaphors of arrows and cycles incapable of capturing the temporal multiplicity of evolution (Gould 1987, Winfree 1987a, Coveney and Highfield 1990). Philosophical concepts alive to recent research in the earth and life sciences concerning the nature of time in relation to a differential multiplicity of biological rhythms are capable of initially unsettling and eventually transforming the causal assumptions deeply sedimented in syntheses of evolutionary theory. A new concept of evolutionary time is exigent, one with the capacity to conceptualize the temporal multiplicity of evolutionary processes and the patterns they produce. Recent research into the problem of biological time (Winfree 2001, Nobel 2017, Ibanez 2017) demands a new conceptualization of the temporal nature of evolutionary processes and the patterns they produce, which in turn illuminates the evolutionary nature of biological rhythms and their cellular and molecular mechanisms.

In The Power of Movement in Plants (1880), Charles Darwin shared nascent insight into the cyclic patterns of plants in relation to oscillations of lightness and darkness, and before Darwin, Carl Linnaeus fashioned a 'floral clock' (1751), demonstrating (and therein predicting) variation in the movements of foliage, measuring the blooming of specific coloration in connection with the time of day (Harper 1977). The flourishing field of chronobiology has turned the insights of Darwin and Linnaeus into a full-fledged field of research programs with impressive records of empirical success—the Nobel Prize perhaps marking the pinnacle. The rapid pace of compelling research on circadian rhythms is impressive, producing experiments and models with wide-ranging ramifications, for physiology and medicine, but also for evolutionary theory. When circadian rhythm research is combined with work on other forms of biological time (Winfree 1987a, 2001, Foster and Kreitzman 2004), the nature of time becomes an exigent problem for theories of evolution. The multiplicative temporal processes readily inferred from the array of biological processes studied by chronobiology and related disciplines conflict with assumptions concerning the nature of time tacitly operative in most models of evolutionary processes. Circadian rhythm research has yet to draw conclusions about the deep history of these endogenous rhythms, the evolution of the molecular mechanisms determining their modes and tempos. Though biologists have studied organismic temporal rhythms with evolutionary concerns held in abeyance, evolutionary change illuminates biological time while biological rhythm research catalyzes the conceptualization of evolutionary time.

Applying methods of evolutionary inference to the temporality of contemporary organisms, the latter elude their conceptual resources. The temporal multiplicity of organisms adduced by chronobiologists exceed standard metrical, experimental, and inferential methods, as exhibited in research dedicated to biological rhythms. Circadian rhythms are ubiquitous, and in the light of evolution, inferred to be one of the most ancient adaptations. Due to standard idealizations of evolutionary and developmental causality, whereby the ultimate causal efficacy of the former must be investigated independently from the proximate causal efficacy of the latter. The features of organisms are accordingly treated by evolutionary biologists as adaptations from which ultimate causal inferences about why these features originated and the gradual actualization of these adaptations over deep time. The features of organisms are treated differently by developmental biologists, as functions, from which proximate causal inferences are drawn. The methodological division of labor between evolutionary and developmental biology has unconsciously hardened the dichotomous causal idealization. The evolutionarydevelopmental movement has long served as a driving force of the EES, a natural outgrowth of its primary agenda, namely to overturn this division—both its conceptual and practical consequences. The physical, genetic, cellular, mathematical, and chemical models of biological rhythmicity are highly nuanced. The fine-tuned modeling and rigorous conceptual architecture of chronobiology offer a compelling account of the timing of ontogenetic functioning. Evolutionary problems are suspended from the account from the start, just as chronobiological problems of ontogenetic functioning are suspended at the start of an evolutionary account of the adaptive advantages and selective histories of (say) circadian rhythms. Although the discovery of deep time enabled evolutionary thought, especially in the work of Darwin, evolutionary theory has ironically neglected or altogether jettisoned a concept of evolutionary time, the nature of which readily became unimportant to the assumptions, structures, and predictions of evolutionary syntheses after the geological breakthrough. The concept of time does not play a fundamental role, indeed plays no ostensible role at all, in conceptualizing the synthesis of evolutionary process. Negligence of the nature of evolutionary time renders evolutionary theory susceptible to the unconscious opportunism of time's subordination to movement.

Together with the problematization of temporality in sciences dedicated to biological rhythms, geology and paleontology have also forced new consideration of temporality, this time evolutionary time. With the coalescence and rise to prominence of the MS, the roles of geology and paleontology were relegated to a supplementary role as biology, specifically genetics, assumed the dominant role in assembling the inferences at the nexus of the synthesis. The conflicting inferences of geology and paleontology are left in abeyance, or otherwise overridden by those of the biological sciences. The sidelining of the disciplines is in evidence at the inaugural conference dedicated to the formalization of the MS (1947), which failed to integrate leading figures in geology and paleontology. Notably George Gaylord Simpson (1902-1984), likely the most influential paleontologist of the first half of the 20th Century, was absent from the synthesis, despite the success of his magnum opus, *Tempo and Mode of Evolution* (1944), which precisely attempts to synthesize paleontology with genetics and the mechanism of natural selection. It is hard not to presume that the conspicuous and suspicious absence of geology and paleontology from the MS is explained by its incapacity to integrate the multiplicity of tempos and modes implicated or explicitly ascribed to the evolutionary process by these disciplines. Instead of configuring a place in the structure of the MS for problem agendas such as these various modes and tempos, the engineers of the synthesis downplay the discoveries of and inferences drawn from these disciplines, effectively writing them off as ultimately trivial anomalies.

The neglected role of paleontology can be understood as a consequence of the gradualist eclipse of the problem of evolutionary time. The methodological relation between the fossil record and evolutionary inference in Darwinian theories smooth over tempo variation indicated by the former with the evolutionary inference of gradualism. Darwin argued accordingly that the stratigraphic record of geological processes erased intermediate forms (or *missing links*) due to its incompleteness, and thus that inferences drawn from the fossil record contributes very little to evolutionary explanation relative to inferences drawn from the study of contemporary organisms, their functioning, and roles in populations and species. A revolution percolated in the pioneering work of G.G. Simpson (1902-1984), which formed the bedrock concepts and programmatic problems pursued by paleontology during the 20th Century, but the evolutionary implications of that revolution were sidelined by consensus evolutionary theory, including the pioneers of initial

MS frameworks, which challenged the universal gradualism and exclusive mechanism of evolutionary change built into the cores of Darwinian theories. Simpson's *Tempo and Mode in Evolution* (1944) affirmed the importance of evolutionary time, but the paleontological rescue of the problem of geological time in evolutionary theory had to wait until "the paleobiological revolution" of the 1970s and 1980s (Sepkoski 2009). This revolution gave rise to *evolutionary paleontology,* which is methodologically distinguished from *organismic paleontology* (Turner 2011). Use of the term "paleobiology" signaled participation in a new phase of paleontology in relation to evolutionary theory, especially cultivated in the journal *Paleobiology* (1975-present), which aimed to empower its role in the assumptions and structures of the consensus synthesis.

The continuous variability of time as the pure form of change enables the stratigraphic passive and active temporal syntheses (or modes of repetition) observable of earth. Chapter 5 thinks through Deleuze's transformation of Kantian synthesis, enabling the conceptualization of time's modes and tempos in distinctive relation to time itself. The concept of rhythm in Deleuze (1994, 2004, 2013) and in his work with Guattari (1972, 1980, 1991) prepares for an explication of the role of the passive and active temporal syntheses, as it is situated within the larger philosophy of difference and becoming created in the works under consideration. The role of the temporal syntheses must be conceptualized under the rubric of repetition and difference, but also under the rubric of time as the pure and empty form of change, a rubric resultant of the Copernican turn in temporality. The purpose of the final chapter is to assemble the cyclic repetitions of biological rhythms with the deeper rhythms of evolutionary change. The temporal syntheses central to Deleuze's philosophy are rich resources to mine for the sake of embracing this uniquely philosophical task. Time itself is conceptualized as the pure and empty form of change, as *continuous variability*, whose modes and tempos are synthetically actualized by *cadence-repetition* and *rhythm-repetition* (Deleuze 1994, 21). The active and metrically equivalent periods of time characterizing cadence-rhythms are conditioned by the far more pervasive passive and unequal punctuations of time characterizing rhythm-repetitions. Individual differences are not mediated via identities, similarities, or oppositions. Difference relates differences through repetition. Variation is the differential element constitutive of repetition, the internal insurance of repetition's productive capacity of differentiation in any repeated instant. The infinite variation of the universe is not necessitated by predetermined plans perpetuating sameness, but by the repetition of pure differences.

The three passive and active temporal syntheses Deleuze develops in *Difference and Repetition* are used to conceptualize the differential actualization of evolutionary and biological rhythms: (1) habit, which 'prioritizes' the present, what Deleuze calls the *living present*, as a contraction of the past; (2) memory, which prioritizes the past as the pure fullness of any given present, in a bifurcating relation of coexistence with the living present, enabling it to pass; and (3) the new, which prioritizes the future, and refers to the productive processes of temporality so pertinent to problems of evolutionary modification. The irreducible modalities of metamorphosis are asymmetrical temporal syntheses coexistent upon a plane of continuous variation. Past, present, and future are not separate parts of time but rather operative dimensions of one another, alternately acting on one another across series of events (or becomings). When the present contracts the past, the past and future are the dimensions of its becomings (first synthesis); when the pure past as an open whole creates a coexistence between the past and the present, the present and future are the dimensions of its becoming (second synthesis); and when the future produces the new the past and future dimensions of its becoming contingently actualize. The philosophical conceptualization of time relates to physical, psychological, biological, and otherwise empirically tractable temporal modes in *transversal* ways, which means in ways that cut across these modes with *consistency*. Time in this philosophical sense is not presumed in the dissertation to determine how these modes "hang together," but it does claim to determine how the problems of the EES hang together, or coexist in their different modes and tempos.

Paramount to Deleuze's philosophy of time is time's long subordination to and relatively recent freedom from *movement*, including chronometric movement. The problem of time has perplexed philosophers for most of philosophy's history, and continues to perplex philosophers today. The various encounters with the problem of time one finds in the history of philosophy all illegitimately subjugate temporality to motion, as expressed in Deleuze in *Cinema 2: The TimeImage* (1985/2013)—an engagement with time focal to Deleuze's philosophy of time, and resonant with his other engagements with temporality (Deleuze 1966, 1994a; Deleuze and Guattari 1987, 1994b). The varied subjugation of time reckons time homogenous, invariantly passing with equal intervals, chronometrically captured, and linear in directionality, determining temporal singularities or anomalies as non-trivial events, as exceptions to the temporal rules of regularity. Deleuze offers a snapshot of the history of time's subordination in the following passage (Deleuze 2013, 39):

> **…if it is true that aberrations of movement were recognized at an early stage, they were in some sense corrected, normalized, 'elevated,' and brought into line with laws which saved movement, extensive movement of the world or intensive movement of the soul, and which maintained the subordination of time. … For a long time aberrations of movement were recognized but warded off. In fact, we will have to wait for Kant to carry out the great reversal: aberrant movement became the most everyday kind, everydayness itself, and it is no longer time that depends on movement, but the opposite…**

The inversion of time's subordination is fostered by the work of Isaac Newton (1642-1727) and Gottfried Leibniz (1646-1716), spurring what Deleuze calls "a Copernican turn in temporality" (Deleuze 2013, 271) in the work of Immanuel Kant (1724-1804), analogous to the paradigm shift from the earth-centric Ptolemaic model of the ostensible cosmos to the heliocentric model of our solar system (section 3). Time is no longer dependent upon or derived from movement. Movement now takes place *in* time. Time and space are pure and immutable forms independent and autonomous from changes and movements in time and space. Time is no longer "numbered movement," no longer chronometrically captured movement. Time is freed from its support role as the measurement of movement. Time assumes a new status of *independence* and *autonomy* (Kant 1998, depending only on itself, as the *pure and empty form of change*, as *continuous variation* (Deleuze 2004). Time takes a novel form of ordinary everydayness, whereby movements outside of the norm are not judged according to an eternal heaven of immutable forms, nor coerced into standard modes of measurement, but rather related to the productive advent of the new. The aberrant movements of the earth depend on the pure and empty form of change for a multiplicity of directions, not merely on cyclic and linear movements measured by chronometers. Temporal measurement is a mode of time, but a derivative mode of time. Time as the pure and empty form of change, as continuous variation, is for Deleuze the transcendental condition of the three forms of repetition, which Deleuze explicates in terms of three *passive* syntheses of time (Deleuze 1994, 2013), a philosophical experiment with Kant's active synthetic approach, which follows through with the revolution spurred by Newton and Kant. The final chapter thinks through Deleuze's transformation of Kantian synthesis, enabling the conceptualization of time's modes and tempos in distinctive relation to time itself. The concept of stratigraphic time fosters development of this relation as a concept of evolutionary time apt to synthesize the problem agendas of the EES with philosophical consistency.

The Extended Evolutionary Synthesis in the Light of Stratigraphic Time

Stratigraphic time conceptualizes the virtual multiplicity of evolution and its modes and tempos of "creative actualization." If "[i]t is enough to endow time with its true meaning of creative actualization for evolution to find a principle which conditions it" (Deleuze 1994, 216) then philosophy's role in relation to evolutionary theory is crucial, as science is not geared toward the problem of time. The thesis that time conditions evolution does not imply a hierarchical relation of explanatory power between philosophy and science. "It is foolish for philosophy to place itself above science," writes Godfrey-Smith, "but it can certainly step back from science and gain an outsider's viewpoint. … The philosopher's vantage point makes it natural to question things that might be taken for granted, perhaps for practical reasons, within scientific work" (Godfrey-Smith 2014, 4). Philosopher Willard Van Orman Quine (1908-2000) pioneered a still prevalent postulation that 'naturalistic philosophy' is only legitimate when it is "contained in natural science" (Quine 1969, 83). Quine's kind of naturalism "gives up the autonomy of philosophy with respect to the choice of questions" (Godfrey-Smith 2001, 284). According to GodfreySmith's characterization of the philosophy of nature (explicated in section 5), resonance between its concepts and the propositional principles of natural science make sense of the natural world, but such resonance does not determine the questions philosophers of nature pursue. The autonomy of philosophy is necessary "for philosophy to be able to pursue the task of seeing how the message of one part of science relates to that of another, and how everything hangs together.

A philosopher will look at how the message of one part of science relates to that of another, and how the scientific view of nature relates to ideas we get from other sources" (Godfrey-Smith 2014, 4). The problem of conceptually assembling the problem agendas of the EES with consistency is specially suited for the conceptual resources of philosophy of nature, as characterized by Godfrey-Smith (section 5), and carried out in the final chapter of the dissertation through the multi-component concept of stratigraphic time.

Godfrey-Smith's reckoning of the philosophy's independent yet interconnected relation of equality to science resonates with the demarcation between the plane of reference upon which scientific propositions function and the plane of immanence upon which philosophical concepts become always new (Deleuze and Guattari 1994, 58-59):

> **Can we say that one plane is 'better' than another or, at least, that it does or does not answer to the requirements of the age? What does answering to the requirements of the age mean, and what relationship is there between the movements of diagrammatic features of an image of thought and the movements or sociohistorical features of an age? We can only make headway with these questions if we give up the narrowly historical point of view of before and after in order to consider the time rather than the history of philosophy. This is a stratigraphic time where 'before' and 'after' indicate only an order of superimpositions. … Philosophical time is thus a grandiose time of coexistence that does not exclude the before and after but superimposes them in a stratigraphic order. It is an infinite becoming of philosophy that crosscuts history without being confused with it.**

The concept of time in *What Is Philosophy?* is an inconspicuous yet eminently important theme of the work, which aims to "consider the time rather than the history of philosophy" (Deleuze and Guattari 1994, 58). The concept of *stratigraphic time* is the function of the title-provoking problem of *What Is Philosophy?* The concept of stratigraphic time is created by Deleuze and Guattari, explicitly in *What Is Philosophy?* (1991) and operatively in *A Thousand Plateaus* (1987), in connection with leading physical and biological theories of time. Stratigraphic time transforms how we think about singular events, evolutionary and developmental rhythms, their contingently and causally determined interactions, conceptualizing their irreducibility to chronometrically determined befores and afters (Deleuze and Guattari 1994, 27). Stratigraphic time makes sense of how these strata of processes "hang together" (Sellars 1962, 369, GodfreySmith 2014), how their differences are passively and actively synthesized, without depending on time's subordination to movement available to measurement: "This is a *stratigraphic time* where 'before' and 'after' indicate only an order of superimpositions" (Deleuze and Guattari 1995, 58). The superimposed strata of sedimented sequences shift in and out of composition with one another in linear and non-linear—metric and non-metric—ways across multiple scales of time. The linearity of chronologically ordered sequences of history is in no way mutually exclusive with the non-linearity of non-chronologically actualized series of becoming (Colebrook 2009).

Assemblages of philosophical concepts and evolutionary problems are assemblages of different temporalities. Science *relinquishes* the infinite speed of chaos "in order to gain a reference able to actualize the virtual" (Deleuze and Guattari 1991, 118). Science creates simplified frameworks, or planes of reference, constructed to slow phenomena down, and to propositionally organize the observations, measurements, functives, inferences, and so on, making up an evolutionary synthesis, for instance. Stratigraphic time is the temporality of philosophy, as distinguished from science's *ramified* temporality: "Science is not confined to a linear temporal succession any more than philosophy is. But, instead of a stratigraphic time, which expresses before and after in an order of superimpositions, science displays a peculiarly serial, ramified time, in which the before (the previous) always designates bifurcations and ruptures to come, and the after designates retroactive reconnections" (Deleuze and Guattari 1994, 125). Evolutionary theory has almost unanimously, and most of the time unconsciously, relinquished the problem of time in acquiescence to antiquated assumptions about the nature of time, entrenching a tacit evasion of novel conceptualizations of evolutionary time. Evolutionary theory assumes the invariant passage of time, merely linear directionality, a gradual pace of modification, and time's reducibility to chronological measurement, thus *idealizing* evolutionary time in the critical sense Godfrey-Smith accords to such simplifications.

Philosophical concepts are not discovered, they are created (Deleuze 2001). The concept of *deep time* is often claimed to have been *discovered*, which no doubt refers to the massive and mounting density of data determining the age of earth far older than previously presumed, but the concept of deep time did not lie dormant in the subterranean strata of data waiting, as it were, for a geologist to discover it. The concept was created by geologist James Hutton in his masterpiece, *Theory of the Earth* (1795), after decades of observation and interpretation of earth's movements. Popularization of *deep time* does indeed depend on the weight of generations of recorded observation, measurement, and scientifically derived inference, but the concept had to be created in an act of thought, a mode of thought different than the observant, metrical, and inferential modes of thought. The scientific activities and discoveries accrued despite their disruptive potential if assembled in expression, if conceptualized in relation to the commonplace biases with which they implicitly clashed. The creation of the concept demanded tremendous will of thought in the face of dangerous consequences, but more so, in the face of the sheer force of entrenched habit of thought—such as cosmological systems of belief, especially those of the anthropocentric sort. The philosophical act was different than the geological acts of thought, which are different than the mathematical acts of thought, the physical, and other salient scientific acts of thought assembled to the concept of *deep time*—"they work differently, they're completely different operations, but they never stop interpenetrating" (Deleuze 1996). Philosophical concepts are not identities abstracted through inferential generalization from concrete particulars, but rather stratigraphic multiplicities of continuous becoming. Picking up from the quotation above, Deleuze speaks of philosophy not as an act of abstraction but as an act of creation, emphasizing the differential assemblage of philosophical creations with other creations of thought (Ibid):

> **When philosophy is thought abstract, the history of philosophy is abstract to a second degree, since it does not consist of speaking abstract ideas, but of forming abstract ideas about abstract ideas. For me, philosophy has always been something else. You can understand what philosophy is—that is, the extent to which it is not abstract, that it is no more abstract than a painting or a musical work—only through the history of philosophy ...**
> **provided that it is properly conceptualized. What might that be? One thing that seems certain to me is that a philosopher is not someone who contemplates or even reflects. A philosopher is someone who creates, and creates a very special kind of thing, creates concepts. Concepts do not exist ready-made in heaven like stars we gaze upon. Concepts must be created, fabricated.**

Concepts are not simple. They are constructed of manifold components: "there are no simple concepts. Every concept has components and is defined by them. It therefore has a combination. It is a multiplicity" (Deleuze and Guattari 1994, 16). A concept is neither a summation derived from ostensibly unconnected or underdetermined data, nor an otherwise emergent inference from empirical cases, but rather a *juncture* (Plotnitsky 2012, 20). These manifold patterns produce conceptual *heterogenesis*—"an ordering of its components by zones of neighborhood" (Deleuze and Guattari 1994, 20). A concept is always in the process of heterogenesis, which involves *internal variation*, a condition of conceptual *consistency* amid the multiplicity of components. The problem of the consistency of concepts concerns internal and external components—specifically how intra-assemblage components and inter-assemblage components *hold together* "with passage and relay" while preserving their heterogeneity: "…from the moment heterogeneities hold together in an assemblage or interassemblage a problem of consistency is posed, in terms of coexistence and or succession and both simultaneously" (Deleuze and Guattari 1987, 327). The temporal nature of conceptual consistency invoked at the end of this passage from *A Thousand Plateaus* (1980) is a harbinger of the subterranean current of Deleuze and Deleuze and Guattari's philosophy of time exhibited in their conceptualization of scientific, artistic, and philosophical creations in *What Is Philosophy?* (1991). Philosophical concepts are heterogenous assemblages constructed of components within and without philosophy, and constructed in an infinite process of becoming in productive resonance and tension with past, present, and future assemblages. They maintain a membrane, as it were, which is attracted by and also attracts other creations of thought, including scientific propositions, artistic affects and percepts, as well as other philosophical concepts. Concepts are thus in a constant state of evolution, of metamorphosis, of heterogenesis. The differential encounters between the components of intra-assemblage and inter-assemblage components is "always new," always becoming (Deleuze and

Guattari 1994, 5). The continuous variation of philosophical concepts is in evidence across the works of Deleuze and his joint works with Guattari.

One especially dynamic case of heterogenesis is the concept of *intensity*, a conceptual transformation explicated in a preface to *Logic of Sense* (2006, 65-6), and a concept prescient to the current project (the key to Chapter 3). The concept of time to which the second half of the dissertation is dedicated—*stratigraphic time*—is like the concept of intensity in that the dissertation extends the concept outside the multiple components originally constructing it in *What Is Philosophy?* Intensity in *Logic of Sense* (1969) takes on quite different components than those constitutive of the concept in Deleuze's previous work, *Difference and Repetition* (1968). While its first assemblage of components (1968) primarily conceptualize the dimension of depth, the second assemblage of components (1969) primarily conceptualize the dimension of surface. When Deleuze joins forces with Guattari in *Anti-Oedipus* (1972), published just three years later, the heterogenesis enters a third phase of becoming, independent from the subordinating rule of static identity. Intensity no longer concerns dimensions of depth and surface, but is rather related to *events*. Intensities actualize on a *body without organs*. Daniel Smith (2012) proposes a third phase of conceptual transformation to Deleuze's chart of changes, a concept of intensity relating to the concept of concept itself in *What Is Philosophy?* In 1991 the status of conceptual components are determined as intensive in nature, rather than extensive (as in the work of Gottlob Frege). The singular determinations of these new component concepts and their relations are temporarily left in abeyance. The main point here is that the concept of intensity and its internal variations exemplify concept creation, as an engine of novelty, of continuous variation, but which also maintains consistency.

Stratigraphic time's encounter with the problem of evolutionary time and of the reconceptualization of the EES problem agendas demands new components, just as the problems of *Logic of Sense* catalyzed component creation different from *Difference and Repetition* with its different problems. The internal variation of stratigraphic time is the condition for its capacity to assemble the EES problems with consistency through a bottom-up approach to the rapid accrual of pertinent data, which demands the plasticity of the concept, its capacity to become newly assembled in its components in relation to the call of solicitors composing the heterogenous orchestra of evolutionary science and philosophy. The new components created in the dissertation connect with and create anew Deleuze and Deleuze and Guattari's conceptualization of time, which resonates and interferes with physical theories of time, but is also, to a significant degree, derived from the life sciences and biological theory, especially embryology and the work of Raymond Ruyer (1902-1987), Georges Canguilhem (1904-1995), Jacques Monod (19101976), Andre Leroi-Gourhan (1911-1986), and Francois Jacob (1920-2013), among others.

Philosophical concepts are not identities abstracted through inferential generalization from concrete particulars, but rather stratigraphic multiplicities of continuous becoming. Concepts are constructed of manifold components: "there are no simple concepts. Every concept has components and is defined by them. It therefore has a combination. It is a multiplicity" (16). A concept is neither a summation derived from ostensibly unconnected or underdetermined data, nor an otherwise emergent inference from empirical cases, but rather a *juncture* (Plotnitsky 2012, 20). These manifold patterns produce conceptual *heterogenesis*—"an ordering of its components by zones of neighborhood" (Deleuze and Guattari 1994, 20). A concept is always in the process of heterogenesis, which involves *internal variation,* a condition of conceptual *consistency* amid the multiplicity of components. The problem of the consistency of concepts concerns internal and external components—specifically how intra-assemblage components and inter-assemblage components *hold together* "with passage and relay" while preserving their heterogeneity: "…from the moment heterogeneities hold together in an assemblage or interassemblage a problem of consistency is posed, in terms of coexistence and or succession and both simultaneously" (Deleuze and Guattari 1987, 327). The temporal nature of conceptual consistency invoked at the end of this passage from *A Thousand Plateaus* (1980) is a harbinger of the subterranean current of Deleuze and Deleuze and Guattari's philosophy of time exhibited in their conceptualization of scientific, artistic, and philosophical creations in *What Is Philosophy?* (1991). Philosophical concepts are heterogeneous assemblages constructed of components within and without philosophy, and constructed in an infinite process of becoming in productive resonance and tension with past, present, and future assemblages. They maintain a membrane, as it were, which is attracted by and also attracts other creations of thought, including scientific propositions, artistic affects and percepts, as well as other philosophical concepts. Concepts are thus in a constant state of evolution, of metamorphosis, of heterogenesis. The differential encounters between the components of intra-assemblage and inter-assemblage components is "always new," always becoming (Deleuze and Guattari 1994, 5). The continuous variation of philosophical concepts is in evidence across the works of Deleuze and his joint works with Guattari.

Stratigraphic temporality assembles the creative modes of philosophy, science, and art, the primordial modes of thought in creative confrontation with "chaos"—uniquely conceptualized in two ways, the first of which is explicitly temporal: as "the infinite speed with which every form taking shape in it vanishes" and as "a *virtual* containing all possible particles and drawing out all possible forms, which spring up only to disappear immediately, without consistency or reference" (118).[1] The philosophy of Deleuze and Guattari casts a wide net into chaos, voraciously venturing

[1] Deleuze and Guattari create a unique concept of chaos, in resonance and interference with the concept of chaos variably cultivated in mathematics, philosophy, and physics, but in some ways new. See Jeffrey Bell (2006), *Philosophy at the edge of chaos: Gilles Deleuze and the philosophy of difference*; Daniel W. Smith (2012), Chapter 8: "Analytics: *On the Becoming of Concepts*"; Arkady Plotnitsky (2012): "From Resonance to Interference: The Architecture of Concepts and the Relationships among Philosophy, Art and Science in Deleuze and Deleuze and Guattari"; and Leonard Lawlor (2012): "Phenomenology and metaphysics, and chaos: on the fragility of the event in

beyond disciplinary bounds, treating philosophy, art, and science (including mathematics and physics) as equally creative modes of thought. While the distinctive modes are inextricably entwined in their creations, they "provide points of reference from which to assess and explore the resonances and exchanges," writes Daniel Smith, the becomings "that take place *between* these three domains (as well as medicine, politics, psychiatry, and so on)" (Smith 2012, 127). The separable domains enable the conceptualization of their interconnections, their milieu, the relational assemblages determining their mixed creations. The philosophical conceptualization of the assemblage of problem agendas structuring the EES must cogently distinguish between philosophic and scientific creations in order to prevent illegitimate interaction between the respective domains. "Deleuze and Guattari are self-aware," writes Michael James Bennett, "they aren't doing defective science but philosophy of nature" (Bennett 2019, 91). They are careful not to misuse scientific propositions in their work, "realiz[ing] the dangers of citing scientific propositions outside their own sphere. It is the danger of arbitrary metaphor or of forced application" (Deleuze 2013, 129). These dangers generated debates in the 90s and early 2000s about the illegitimate employment of scientific concepts or propositions, and about the illegitimate interpolation of philosophical concepts in scientific domains (Sokal and Bricmont 1998, Plotnitsky 2002, Plotnitsky 2012). Deleuze suggests that "perhaps these dangers are averted if we restrict ourselves to taking from scientific operators a particular conceptualizable character which itself refers to nonscientific areas, and converges with science without applying it or making it a metaphor" (Deleuze 2013, 129). Deleuze is clear as day on many occasions that he is not "speaking metaphorically" (Deleuze 1990, 76; 1994, 25, 181, 190;

Deleuze."

1989, 57). Deleuze's resistance to metaphorical speaking is motivated by its implication of Platonic philosophy, whereby the ascent of the soul moves from "meanings sedimented in language in the order of discovery (instants, copies) to those later discovered but prior in the order of being (forms)" (Bonta and Protevi 2004, 113).

Stratigraphic time is a new way to conceptualize what Darwin called the *insensibly graded series* of evolution, illuminating the multiplicity of rhythms determining evolutionary processes and products through the four structural components: (1) *developmental plasticity*, (2) *developmental bias*, (3) *inclusive inheritance*, and (4) *niche construction* (Laland 2015 et al.). Stratigraphic time expresses and exemplifies the multiplicity of processes connecting molecular, biological, geological, climatological, cognitive, and other clocks important to the assumptions, structures, and predictions of the EES. Stratigraphic time makes sense of how the four multiplicities of processes interact, assemble, and change through myriad modes and tempos of variation and selection over phylogenetic and ontogenetic scales of time. Philosophical concepts alive to recent research in the earth and life sciences and adjacent fields concerning the nature of time and evolution are capable of initially unsettling and eventually constructing a conceptual assemblage capable of transforming the causal assumptions deeply sedimented in syntheses of evolutionary theory. A new concept of evolutionary time is exigent, one with the capacity to conceptualize the temporal multiplicity of evolutionary processes and the patterns they produce. Evolutionary theory has almost unanimously, and most of the time unconsciously, relinquished the problem of time in acquiescence to antiquated assumptions about the nature of time, entrenching a tacit evasion of novel conceptualizations of evolutionary time. Evolutionary theory assumes the invariant passage of time, merely linear directionality, a gradual pace of modification, and time's reducibility to chronological measurement.

Philosophy of Nature, Philosophy of Science, and Science

Godfrey-Smith begins *Philosophy of Biology* (2014) by parsing two philosophical approaches to biological problems. Reference is made to Wilfred Sellars' famously succinct formulation of philosophy to convey the first approach: "The aim of philosophy, abstractly formulated, is to understand how things in the broadest sense of the term hang together in the broadest sense of the term" (Sellars 1962, 369, Godfrey-Smith 2014, 1). The concept of stratigraphic time expresses and exhibits how broad processes assembled by evolutionary biologists "hang together," how they are synthesized, and the resultant inferences salient to philosophers, but it also expresses and exhibits the second approach to philosophy, which Godfrey-Smith likens to an "incubator of theoretical ideas, a place where they can be developed in a speculative way while they are in a form that cannot be tested empirically" (Ibid). Philosophical concepts beyond empirical tractability and testability have often potentiated future science. Prime biological examples are of course inheritance and the gene, concepts expressing processes inferred from available data in lieu of direct observation and experimentation.

Arthur Winfree—a major influence on the present effort—articulates the importance of concepts or theories as catalysts of scientific observation and inference: "As often happens in science, theory set[s] the stage for recognizing phenomena that had already been recorded, but somehow could not be perceived until a conceptual home had been created for them in the minds of scientists" (Winfree 1987, 65). Winfree heeds a peculiar temporal interaction of resonance and interference between philosophy (or theory) and science, which begins with the scientific capture of phenomena through recording procedures and devices. The recording of phenomena inevitably eclipses the intensive forces actualizing the phenomena observed and measured. The phenomena recorded becomes illuminated by the light of philosophical concepts that "seem to roam far from actuality" (Godfrey-Smith 2014, 2). When Godfrey-Smith characterizes the incubator mode of philosophy as *separate* from and *secondary* to the Sellars sense of philosophical activity (Godfrey-Smith 2014, 1), the modal and temporal relations between them do not entail an order of explanatory exigency, power, or primacy.

Darwinian Populations and Natural Selection (2009) made a major impact on the philosophy of biology and evolutionary theory by adopting a form of the first approach, which Godfrey-Smith calls *philosophy of nature* (2009, 2011, 2014). *Philosophy of nature* aims to make sense of life's purpose on earth and how life fits into the universe. Just as the concept of deep time loosened up perspectives on the place of humans in the universe, philosophy of nature attempts to loosen perspectives on the package of evolutionary-developmental characteristics of life by enabling people to "see the world as open to possibility rather than bound up with duty and purpose" (Godfrey-Smith 2011, 08:38-08:43). "Philosophy of nature in my sense," he writes, "comes *after* empirical science" (Godfrey-Smith 2001, 284). After in practice, not in explanatory efficacy. Evolutionary biology in connection with adjacent fields become "an instrument—a lens—through which we look at the natural world. Science is treated as a resource for philosophy rather than a subject matter" (Godfrey-Smith 2014, 4). Godfrey-Smith's tripartition of science, philosophy of science, and philosophy of nature is instructive (Godfrey-Smith 2009, 2-3):

(1) *Science*: "The focus of science is the natural world. Science investigates the world not with a rule-governed 'method,' but with something more like a *strategy*." The strategic investigation of the natural world leads the formulation of theoretical principles concerning its processes. The success or failure of these principles is determined by observation and measurement. One scientific exigency includes the explication of the inner logic of theories, critically considering their empirical resources, explanatory powers, and how effectively they connect and resonate with other theories.

(2) *Philosophy of Science*: "The focus of the philosophy of science is science itself, the process described just above. The aim is to understand how science works and what it achieves." Philosophers of science think about how theories relate to the natural world, how their representations function to produce knowledge of the natural world. They also evaluate empirical support for these representations. This kind of philosophical work problematizes "the nature of evidence, testing, and scientific change. Such work can cast its net widely, to capture all of science, or narrowly, to comprehend a small part of it, such as evolutionary biology."

(3) *Philosophy of Nature:* "Now the focus is on the natural world again. But the focus is on the natural world as seen through the instrument of science." Philosophers of nature work out what the "real message" of scientific work means in its broader implications concerning our niche in nature. Science is not used in an uncritical fashion by such philosophers, it is not handed down in its "raw" form with transparent meaning. Science must be worked out, philosophically, to determine its message, which philosophers of nature use "to put together an overall picture of the world" (Godfrey-Smith 2014, 4).

Philosophy of nature as articulated by Godfrey-Smith (2011) aims to makes sense of life's purpose on earth and how life fits into the universe. Just as the concept of deep time loosened up perspectives on the place of humans in the universe, philosophy of nature attempts to loosen perspectives on the package of evolutionary-developmental characteristics of life by enabling people to "see the world as open to possibility rather than bound up with duty and purpose" (Godfrey-Smith 2011, 08:38-08:43). Philosophy of nature is an approach explicitly endorsed by

Sterelny (2013) as well as Griffiths and Stotz (2013). Other philosophers associated with the EES are candidates for its style of engaging science and the philosophy of science.

Attention given and contributions made to the construction of an evolutionary synthesis have traditionally come from philosophy of science. The problem agendas of the EES demand the third kind of work, beyond philosophy of science. Philosophy of nature is key to the successful construction of an evolutionary synthesis as it "often aims at synthesizing the results of a number of different scientific fields, working out how they fit together—into a coherent package" (Godfrey-Smith 2009). Philosophers of biology (e.g. Jablonka and Lamb 2005, Pigliucci 2007, Beatty 2010, Love 2010, Griffiths and Stotz 2013, Sterelny 2017) and their colleagues in the sciences (e.g. Odling-Smee, Laland, and Feldman 2003, Müller 2007, Fernando and Szathmäry 2010, Wilson 2010, Cavalli-Sforza and Bodmer 2013) approach the task of rethinking the synthesis of salient sciences and processes in accord with the *philosophy of nature.* These efforts parse and explain how developmental bias, developmental plasticity, inclusive inheritance, and niche construction "hang together" in relation to Darwinian and Modern processes to assemble the extended evolutionary synthesis. Deleuze's philosophy of concept creation is on the surface starkly different in style from philosophy of nature in the contemporary works cited above and below, but the constructive tensions between them are sources of conceptual innovation and impact all around. Deleuze described his philosophical style in many different ways, so the significance of the one time he described it as "philosophy of nature" is difficult to discern (Deleuze 1995, 155). "Biologists are right," affirms Deleuze, "when, in posing the problem of heredity, they avoid allocating distinct functions, such as variation and reproduction, to these systems, but rather seek to show the underlying unity or reciprocal conditioning of these functions. At this point, the theories of heredity necessarily open on to a *philosophy of nature*. It is as if repetition were never the repetition of the 'same' but always of the Different as such, and the object of difference in itself were repetition” (Ibid. 256). Chapter 5 argues that *stratigraphic time* offers the most conceptually compelling and empirically consistent approach to the problem of synthesizing the causal catchalls of the EES. Deleuze writes that the problem of *inclusive inheritance*—"theories of heredity”—open up the exigency of a philosophy of nature propelled by vital concepts of repetition and difference. The approach affirms in the light of Deleuze’s philosophy of nature the prominent problem of evolutionary process as the repetition of difference.

CHAPTER 1. EMBRACING THE PROBLEMATIC STRUCTURE OF THE EXTENDED EVOLUTIONARY SYNTHESIS

Chapter 1 explicates and evaluates the core assumptions of the EES in contrast with the MS, which has served as the dominant conceptual framework for evolutionary science and theory since the early twentieth century, combining previously disparate strands of (1) Darwinian evolution via natural selection, (2) models and concepts from population genetics, as well as (3) Mendelian models of inheritance (Huxley 1942, Mayr and Provine 1988). Evolutionary thought has been forced to encounter empirical discrepancies and resultant theoretic tensions between the MS and the problem agendas pursued by a multiplicity of earth and life sciences, which ostensibly evince nontrivial causalities and contingencies key to understanding the multiplicity of the modes and tempos of evolutionary processes. I explicate and critically evaluate the tacit idealizations of evolutionary temporality and causality central to the structure and content of classic and contemporary evolutionary syntheses with the aim of newly conceptualizing problems pursued by adjacent theoretical traditions and research programs, which contribute to the new, revised, and expanded synthesis: evolutionary-developmental biology (Müller 2017), the study of phenotypic plasticity (Pigliucci 2004), niche construction (Odling-Smee, Laland, and Feldman 2003), the geometry, physics, and philosophy of biological time (Winfree 2001), punctuated equilibrium (Eldredge and Gould 1993), genomics (Griffiths and Stoltz 2013), cell biology (Rose 2003), embryology (Robert 2004), epigenetics (Jablonka and Lamb 2008), technical evolution (Leroi-Gourhan 1993), cultural evolution (Boyd and Richerson 2005), philosophy of nature (Godfrey-Smith 2009), theoretical biology (Varela and Stein 1994), and so on. The multiple methodological techniques, conceptual architectures, inferential strategies, and underlying assumptions unique to each evolutionary discipline creates the venerable problem of *synthesis*. Philosophy of nature is specially suited to the task of conceptually synthesizing the evolutionary and developmental modes and tempos of organisms and their lineages. Geology, paleontology, and biology have played key roles in the construction and transformation of evolutionary theory. The disciplines have all too disparately cultivated these roles, however, giving rise to conflicting assumptions within the theory. Competing attempts to synthesize the respective disciplinary contributions have achieved only modest success. The avowedly problematic structure of the new synthesis embraces the previously neglected empirical exigencies pursued by the connected disciplines, embracing explanatory perplexity in relation to the nature of the processes involved. While the core EES concepts of *reciprocal causality* and *constructive development* free causal multiplicity and ontogeny from unidirectional causality and phylogeny, the EES still subordinates evolutionary time to causal movement. The causal multiplicity and reciprocity admit of variable evolutionary rates of stability and modification, but those rates subordinate time itself to process.

The EES ultimately repeats the gradualist eclipse of deep evolutionary time, even while it explicitly affirms variation in rate. The rationalist conceptualization of evolutionary temporality problematized in Chapter 2 and in Chapter 3 demonstrate a tacit reduction of temporal relations to successively ordered relations between causes and effects. The true problem of deep time is reduced to a rationalist conceptualization of evolutionary time. The unidirectional arrow of evolutionary time is determined by the gradual process of natural selection in assemblage with less causally efficacious processes. The causal relations conceptualized by evolutionary syntheses are simplifications of the multiplicity of evolutionary processes, and as such serve as productive, yet provisional, conceptualizations.

1.1 The Problem of Evolutionary Synthesis

> *[A] curious aspect of the theory of evolution is that everybody thinks he understands it. I mean philosophers, social scientists, and so on. While in fact very few people understand it, actually, as it stands, even as it stood when Darwin expressed it, and even less as we now may be able to understand it in biology.*
>
> Jacques Monod, "On the molecular theory of evolution" (1975, 12)

Biochemists Francois Jacob (1920-2013), Andre Lwoff (1902-1994), and Jacques Monod (19081976) shard the 1965 Nobel prize in Physiology or Medicine "for their discoveries concerning genetic control of enzyme and virus synthesis" (Nobelprize.org 2010). Experimental research on *E. coli lac operon*, specifying how the biochemical system encodes proteins necessary for the breakdown and transportation of lactose, led Jacob and Monod to conceptualize the basic regulatory principle operative in the cellular regulation of all organisms (Ullman 2003). Breakthrough experimental and conceptual determination of biochemical process in the light of evolution surely qualify Jacob, Monod, and their colleagues as some of the "very few people" capable of actually understanding evolutionary theory. The scientists naturally dedicated intermittent if not consistent attention to how their discoveries fit into an overall understanding of the natural world, how molecular problems and concepts resonated and interfered with the problems and concepts not only of evolutionary theory but also of philosophy of nature. Monod's *Chance and Necessity: Essay on the Natural Philosophy of Modern Biology* (1971) is a testament to how alive the author is to the philosophical problems accompanying the rapidly accelerating scientific research salient to evolutionary theory. The work is also a testament to Monod's sensitivity to the exigency of translating the scientific and philosophical problems and concepts of evolutionary theory into prose cogent to the general public. The narrow representation of evolutionary theory to which many advocates and critics relate only scratches the surface of an "actual understanding."

Paleontologist and evolutionary theorist Stephen Jay Gould (1941-2002) echoes Monod's humble affirmation of the persistently perplexing problems evolution provokes—perplexion only multiplied and amplified by the advent of new concepts venturing beyond the basic bones of Darwin's theory (Gould 2002, 27):

> **The intricate and multifaceted concepts that have nuanced and altered the central logic of all three branches [agency, efficacy, and scope] of Darwinism's essential postulates represent ideas of broad ramification and often remarkably subtle complexity, as we vain scientists soon discovered in our fractured bubbles of burst pride—for we had been so accustomed to imagining that an evening in an armchair could conquer any merely conceptual issue, whereas we all acknowledge the substantial time and struggle that empirical problems, demanding collection and evaluation of data, often require. Yet, on these basic questions in formulating evolutionary theory, we often read and thought for months, and ended up more confused than when we began.**

Recent debate over whether evolutionary theory needs a "rethink" (Laland 2019, *Nature* 2014, cf. Carroll 2005 versus Coyne 2005), whether it needs a more robust, rigorous, and compelling contemporary conceptualization, attests to the "more confused" state of actual understanding in the sciences and humanities, attests to the persistence of classic evolutionary problems. The problems have nonetheless become more aware of themselves *as problems* enabling a philosophical mode of conceptual construction apt to synthesize these problems without subjecting them to an overly idealized hierarchy of explanatory priority. To become more confused, more perplexed, by a problem is necessary, though rarely sufficient, for actual understanding. The *problematic structure* adopted in recent decades by an amiable jumble of disciplines dedicated to "actually understanding" evolution opens up a new juncture between science and philosophy compelled by the exigency to conceptualize an extended evolutionary synthesis.

The EES aims to integrate these previously neglected, or otherwise overlooked, empirical exigencies, embracing explanatory perplexity in relation to the problems produced by these discrepancies and tensions. *Stratigraphic time* is a philosophical concept constructed to determine with *consistency* the temporal and causal relations assembling the EES. The need to rethink evolutionary theory, to create a new, revised, expanded or extended synthesis is a false problem according to some (Wray et al 2014), though its status as a true problem has gained gradual yet undeniable traction since the turn of the century (Beatty 2019). Evolutionary biologists Kevin Laland and Tobias Uller, geneticist Marc Feldman, philosopher Kim Sterelny, and others advocate the urgent construction of an EES capable of integrating relatively novel processes compelled by new data pouring from adjacent disciplines—processes key to understanding the expansive scope and multiple scales of evolution. Evolutionary biologists Gregory Wray, Hopi Hoekstra, Douglas Futuyma and their colleagues claim that there is no need to rethink evolutionary theory, that the standard synthesis has successfully modified its structure and content to accommodate new data and the processes inferred from such data. The revisionary nature of the EES warrants earnest suspicion by advocates, despite the ineluctable density of data underdetermined or otherwise undeterminable by the MS, for false problems are prone to pull us into an illusory maze precluding productive flight. "The very notion of the false problem," thinks Deleuze, "indeed implies that we have to struggle not against simple mistakes (false solutions), but against something more profound: an illusion that carries us along, or in which we are immersed, inseparable from our condition" (Deleuze 1966, 20). The status of *true* problem does not guarantee a solution. Problems are unproductively split into soluble and insoluble ones.

One might well wonder, with philosopher Alan Love, if attempts to revise and expand the structure and content of evolutionary theory is not rather presumptuous, considering Monod's sustained suspicion regarding the struggle for most people to understand even the bare bones of the theory. Simply to pose, let alone sufficiently answer, questions of sweeping scope and status such as "Is contemporary evolutionary theory adequate? Does it contain gaps or inconsistencies?

Do we need an expanded or extended evolutionary synthesis (Pigliucci 2007, Müller 2007)?" (Love 2010, 403) runs the risk of creating more confusion than clarity about the theory through speculation, of brazenly violating the scientific principle of parsimony, perhaps even of unwittingly attempting to "reinvent the wheel." The ambition to rethink the structure and content of evolutionary theory is *erroneously* received by critics of a hardened classical bent as audacious, for the revisionary ambition, at least in the case of the EES, readily admits of the insufficiency of our understanding of evolution—hence the very need for revision and extension. Over generations of consolidation, compelled by their pragmatic value to the point of unconscious opportunism (Poincare 1907), idealizations of evolutionary problems have oriented the methodological and inferential methods of the sciences concerned. These nucleating idealizations form the core of evolutionary thought and practice around which an evolutionary synthesis must conform. The conceptual core of the MS has hardened, and consequently attempts to reconfigure the structural and substantial lineaments of the MS have faced many formidable challenges.

Attempts to reconfigure the structural and substantial lineaments of the MS have faced many formidable challenges. These challenges are productively encountered by the conceptual contributions of philosophers of nature and philosophers of science. "The work of defending, expanding, challenging, and, perhaps, replacing the Modern Synthesis," write Grene and Depew, "has tended to bring out the philosopher in many evolutionary biologists" (2004, 248). The turn to philosophy in science is explicitly and tacitly in evidence in the history of evolutionary theory. Monod aimed to conceptualize the global scope of evolutionary theory percolating in the local biochemical system he studied, and it is likely that many other scientists turn philosophers also encountered the deeper problems implied in the smaller problems mobilizing their careers—deeper or more global problems that likely long awaited their explicit attention. The initial formation and rapid growth of "philosophy of biology" from the middle 1980s till now is to a significant degree due to the turn to philosophy within evolutionary biology, a turn rarely referring to itself as philosophical in nature, finding evolutionary *theory* more suitable. “A large proportion of the philosophy of biology is about evolutionary theory,” explains leading philosopher of nature Peter Godfrey-Smith, “as this part of biology unifies much of the rest, has a great deal to say about our place in the universe, and gives rise to many puzzles. Evolutionary change occurs at several levels” (Godfrey-Smith 2014, 28). Thus the multidisciplinary and conceptually manifold nature of the problem of constructing a synthesis capable of integrating the problem agendas crystallizing in salient sciences demands critical collaboration between practicing scientists, scientists turn philosophers, philosophers of science, and philosophers of nature.

Love argues for the importance of philosophy’s role in relation to evolutionary syntheses, a role which demands great patience of the philosopher, who is confronted with a perpetual climb multiple learning curves corresponding to the many disciplines constitutive of evolutionary theory. The finitude of human thought is daily demonstrated by the attempt to think in between disciplines, to synthesize the problematic connections determining the immense, frequently conflicting, and rapidly accumulating data, inferences, functions, assumptions, concepts, theories, methods, and disciplines salient to evolutionary theory. The philosophical mode of thought is uniquely qualified to encounter the challenge of conceptually synthesizing the most important problems driving evolutionary theory. Love draws an epistemological distinction between the *structure* and *content* of evolutionary theory to set up his argument for the crucial role of philosophy. The *content* of an evolutionary synthesis includes key assumptions about the nature of evolutionary processes and patterns, the inferences constitutive of these assumptions, and the empirical work from which these inferences are drawn. The *structure* of an evolutionary synthesis involves the theoretic organization of the content, the isolation of structural components amenable to the diversity of content, and the key causal connections between the structural components. Love reckons that “there is no logical relationship between theory content and structure, even though they have intimate relations with one another” (Love 2010, 408). Various revisions and augmentations of content proposed by alternative conceptualizations of evolution may be consistent with different structures. At the same time, a new representation of structure might or might not demand the differential exclusion or inclusion of empirical content. Exploration of a new synthesis, such as the EES, does not necessarily entail major revisions or augmentations of empirical content. The advent of a new, revised, expanded or extended synthesis requires, according to Love, comparable attention to both content and structure. The EES promotes both new content and new structure. The intimate scientific and philosophical connections between EES structure and content are problematized and conceptualized throughout the entire dissertation.

Love attempts to strengthen the structure of the EES, and specifically the connections between problematic topics, explicating his approach by drawing an epistemological distinction between the *structure* and *content* of evolutionary theory. The *content* of an evolutionary synthesis includes key assumptions about the nature of evolutionary processes and patterns, the inferences constitutive of these assumptions, and the empirical work from which these inferences are drawn. The *structure* of evolutionary syntheses involves the theoretic organization of the content, the isolation of structural components amenable to the diversity of content, and the key causal connections between the structural components. Love reckons that “there is no logical relationship between theory content and structure, even though they have intimate relations with one another” (Love 2010, 408). Various revisions and augmentations of content proposed by alternative conceptualizations of evolution may be consistent with different structures. At the same time, a new representation of structure might or might not demand the differential exclusion or inclusion of empirical content. Exploration of a new synthesis, such as the EES, does not necessarily entail revision or augmentation of empirical content. The advent of a new, revised, expanded or extended synthesis requires, according to Love, comparable attention to both content and structure.

Gould's *The Structure of Evolutionary Theory* (2002) is a prime example of how the distinction between content and structure might operate within and between evolutionary syntheses, which often occurs quite subtly. While a more sustained engagement with Gould's work lies ahead, it is worth briefly characterizing his magnum opus with an eye to how content and structure are distinguished. Despite the title, the foremost target for transformation is not primarily the structure of evolutionary theory. The primary target is transformation of the content included and excluded within classical and current structures. Revisions of the MS advocated in *Structure* consist in the inclusion of new or otherwise unjustifiably excluded content. In order to conceptualize the new problems of content in relation to previous syntheses, Gould and others call for a new synthesis requiring structural modification sensitive to the relevant content. Gould criticizes the structure of classical evolutionary theory as too reductive and exclusive in its choice of constitutive content, of key evolutionary processes, such as species selection, developmental constraints, and patterns of punctuated equilibria. Gould derives the tripartite structure of classical evolutionary theory from the three "branches" of natural selection operative in Darwinism—agency, efficacy, and scope (explicitly addressed in Chapter Four). Gould's suspicion is less directed at the *structure* of evolutionary theory, as such, as to the *content* chosen to be structured by the core "branches" adopted and enhanced by the MS and other standard syntheses. Gould's overarching aim in the second half of the tome is to "revise and expand" the content of these syntheses. 21st Century attempts to usher in a new synthesis have continued to focus on content, but structure has become a more prevalent problem, especially among philosophers concerned with the EES (Callebaut 2010, Laland et al. 2015, Beatty 2019).

The distinction between structure and content functions variably with respect to scientific discipline, compelling Love to adopt a "bottom-up" approach specific to sciences salient to evolution, as opposed to a "top-down" approach attempting to apply the sweeping structure of all science to evolutionary theory (Love 2010, 404). The latter is frequently favored by philosophers and historians of science aiming to track theoretic change over time, and how these changes are confirmed (or not) by empirical data. The "bottom-up" strategy is suited for digging into the details of a theory, and especially well-suited for evolutionary theory, given its multidisciplinary production of data, the density and diversity of which overwhelm idealizations and other generalizations of less audacity. The "bottom-up" approach encounters the field observations, measurements, experiments, inferences, and so on, relatively independently conducted in adjacent evolutionary disciplines as percolators for the isolation of structural components, instead of grafting a "top-down" structural representation of evolution on these disciplines, retrodictively and predictively subsuming the increasing multiplicity of data. Love lists four benefits of the former approach: (1) it facilitates research currently accumulating; (2) organizes the content of a theory in a systematically coherent manner; (3) throws light on the historical development of a theory; and (4) functions as a defense against challenges external and internal (409). All of the strengths of this approach are important to the conceptualization of the EES, but the philosophical insight of the bottom-up strategy key to conceptualizing the structural components of the EES with consistency is *the solicitation of problems*. The difference in approach and the importance of the bottom-up synthetic strategy becomes clearer and more compelling once the nature of the problem is conceptualized.

Love draws a connected distinction, this time between *narrow* and *broad* representations of evolutionary theory—distinctive circumscriptive approaches to the vast variety of content the multiplicity of salient sciences produce. The principles of structural demarcation used to circumscribe boundaries around content determine whether content inclusion is more or less restrictive (or expansive). Relentlessly struggling to defend evolution as a fact and natural selection as the preeminent force of change against critics, often external to the scientific community, proponents of evolution by natural selection turned to narrow representations, which functioned as the default form of representation for pragmatic reasons. They are quick, cogent, and simple articulations of the theory for the purposes of persuading laypersons in other neighborhoods of thought (scientific, religious, educational, and so on). The core content of these representations have become codified as the fundaments of evolutionary theory, relegating other empirical sources of content ancillary or peripheral to these representations of evolutionary processes and patterns. *Narrow representations* normally feature in genetic models and game theoretic models to illuminate mechanisms of modification in populations, integrating diverse causal factors. However efficacious the multiplicity of factors identified might be in determining lifeways, they ultimately orbit the preeminent causal force of evolution—the mechanism of natural selection—and therefore become subsumed by a *causal minimalism* (Godfrey-Smith 2006, 2009), an idealization of evolutionary causality effectively excluding the diverse causal factors from focal explanation. The narrow representations of evolutionary theory are illequipped to capture the heterogeneous content of the MS, which aimed to integrate content excluded by narrow representations, but ultimately narrowly reckoned evolutionary processes and products as controlled by allele frequency changes and explicated through the tools of population genetics (and "population thinking"). If narrow representation is insufficient for the MS, it is quite clearly overwhelmed by the task of formulating an extended synthesis, which demands a broad representation of evolutionary theory derived from a "bottom-up" approach to boundary demarcation.

A *broad representation* of evolution—in contrast with the narrow representation, or idealization, just discussed—is a synthesis of multidisciplinary contributions to fundamental evolutionary problems. Broad representations are obviously more inclusive of content, embracing evolutionary biology's diverse sources of explanatory power by integrating population genetics, theories of hierarchical selection, paleobiology, systematics, speciation, comparative development, geology, biogeography, ecology, and so on. Love directs attention to textbook representations of evolutionary theory to enact a "bottom-up approach" to broad representations. Textbooks capture widespread consensus concerning pertinent empirical content and structural concepts, even though they detrimentally simplify actual scientific activity and disfigure science's historical development (Kuhn 1996). Love scrutinizes broad representations found in textbooks to identify principles of demarcation, finding relatively "consistent and stable domains of problems ('problem agendas') … investigated by combinations of diverse life science disciplines" (Love 2010, 404). The structural concept of *problem* expresses an *erotetic* logic of open-ended components representing series of distinctive yet ultimately connected questions, inquiries into various disciplinary approaches to these questions and how their answers hang together, how they coexist, to broadly represent the theory of evolution. The theory is structured as a *synthesis* due to the problem of creating conceptual consistency between the structural components (or *problem agendas*, the preferred structural concept in the dissertation).

The preeminent problem of philosophy, according to Wilfrid Sellars (1912-1989), concerns "how things in the broadest sense of the term hang together in the broadest possible sense of the term" (Sellars 1962, 369). Love's textbook survey concludes that while some of the better broad representations manage to achieve thematic coverage fit for consensus, they fail to establish robust and compelling connections between the structural components meant to organize the thematic content, suggesting that "a philosophical contribution about structure in a broad representation may be applicable regardless of whether an Extended Synthesis is ultimately formulated" (422).

The dissertation affirms the problematic structure of the EES, and affirms the need of a new conceptualization. Love highlights the weakness of the connections between the structural components of the EES, the problem agendas, or “causal catchalls” in four conceptual multiplicities: (1) *developmental plasticity*, (2) *developmental bias*, (3) *inclusive inheritance,* and (4) *niche construction* (Laland 2015 et al.). *Stratigraphic time* is a new way to conceptualize the connections of the EES, illuminating the multiplicity of differential rhythms determining evolutionary processes, products, and their patterns across deep time. The focal concept of stratigraphic time is created in the second half of the dissertation (and previewed in section 4 of the present introduction). The problem agendas of the EES and how they “hang together,” how they coexist, are problematized in the first half of the dissertation, but prior to explicating, analyzing, and assessing these problem agendas, it is necessary to conceptualize the nature of problems, the problematics of the problem, closely related to the problematics of the concept, and the concept of the concept. The dissertation embraces the problematic structure of the EES in its deepest assumptions. Stratigraphic time is more conceptually apt for the problematic nature of the synthesis, which is not a synthesis in its classic sense. The dissertation affirms the problematic structure of the EES, and affirms the need of a new conceptualization. Love highlights the weakness of the connections between the structural components of the EES, the problem agendas, or “causal catchalls” in the four conceptual multiplicities: (1) *developmental plasticity*, (2) *developmental bias,* (3) *inclusive inheritance*, and (4) *niche construction* (Laland 2015 et al.). Much progress has been made in determining causalities and contingencies constitutive of these multiplicities, but to a lesser extent the connections between them, which are at present very much open for debate (e.g. Sterelny 2003, Jablonka 2005, Piggliuci 2010,). *Stratigraphic time* conceptualizes these connections, illuminating through passive and active temporal syntheses the multiplicity of differential rhythms determining evolutionary processes, products, and their patterns across deep time.

1.2 Classic and Contemporary Synthesis Arguments

The problem of evolutionary synthesis has undergone a series of internal variations, which historically contextualize the problem. Evolutionary biologist and pioneer of the philosophy of biology Ernst Mayr (1904-2005) dedicated the 1947 American Academy of Arts and Sciences conference to defining and formalizing an evolutionary synthesis. The history of evolutionary theory in the 20th Century is generally turbulent, transformation is a rule, and the formation of the synthesis follows suit. Mayr wrote a preface to the new edition of *The Evolutionary Synthesis: Perspectives on the Unification of Biology* (1980) in the late nineties to clarify confusions about the growth of the synthesis, which included a stage prior to what is widely known as the MS. In the earliest years of the 20th Century a synthesis emerged within the field of genetics, between early Mendelian geneticists (William Bateson (1861-1976), Hugo De Vries (1848-1935), Wilhelm Johanson (1857-1927) and Darwinian geneticists (Ronald Fisher (18901962), J.B.S. Haldane (1892-1964), Sewall Wright (1889-1988)), in which their distinctive approaches to the genetic explanation of natural selection find common ground. The former advocated a mutation-based and saltationist theory, and held onto these guiding explanatory postulates until the mid-30s. The relative reconciliation between Darwinian thinking and advances in genetics constitutes a preliminary synthesis, priming the coalescence of the MS from 1937 to 1947. The importance of the evolutionary synthesis was slow to permeate pertinent disciplines, perhaps unsurprisingly falling short of becoming exigent to all relevant fields.

Despite the initial synthesis, tensions intensified between disparate evolutionary disciplines in response to core problems of organic diversification, speciation, adaptation, microevolution and macroevolution, tempos and modes of evolutionary change, mutation and natural selection, chance and directionality, and so on, due to lagging synthetic theoretical momentum. Such tensions ruled the evolutionary community across disciplinary and geographical boundaries until the mid-30s, motivating Mayr to unify the similarities and differences between approaches by identifying shared assumptions and structuring them to present the grand orchestration of evolutionary processes and patterns (what would come to be known as "The Modern Synthesis"). According to Mayr, resolution of the major tensions previously blocking synthesis had been catalyzed by the publication and success of *Genetics and the Origin of Species* (1937) by Theodosius Dobzhansky (1900-1975). Dobzhansky's title clearly indicates an attempt to unify genetic disciplines, which had become increasingly enthusiastic about the gene as the central explainer in evolutionary theory and Darwinians holding onto organisms (involving genes) as the primary targets of evolutionary explanations. Surely Mayr's aspiration of resolution is overzealous, yet alleviation is in evidence, as this paper was followed by the meeting Mayr helped organize for the sake of formally giving birth to the MS. Mayr also published a more rigorous explication of Dobzhansky's synthetic efforts, *Systematics and the Origin of Species* (1942).

Nonetheless, the MS has served as the dominant conceptual framework for evolutionary science and theory since the early twentieth century, combining previously disparate strands of (1) Darwinian evolution by means of natural selection, (2) population genetics and thinking, as well as (3) Mendelian models of inheritance. The MS has had success in identifying, specifying, describing, explaining, and also mathematically modeling changes in the frequencies of genetic variants over time. The multifaceted framework tacitly and explicitly shapes contemporary concerns, research programs, and theories, even though "today's evolutionary theory is vastly more sophisticated than the original synthesis and covers a broader range of phenomena" (Laland et al. 2015, 2). The EES is a conceptual response to problems emerging from thriving theoretical and experimental research programs (evolutionary-developmental biology, the study of phenotypic plasticity, of niche construction, of cultural evolution, cell biology, genomics, epigenetics, behavioral economics, philosophy of nature, etc.). The contributions are different in kind, yet "fit together with surprising coherence. They show that variation is not random, that there is more to inheritance than genes, and that there are multiple routes to the fit between organisms and environments. Importantly, they demonstrate that development is a direct cause of why and how adaptation and speciation occur, and of the rates and patterns of evolutionary change" (Laland et al. 2014, 164). Conceptualization of the components, cultivations of the problem agendas, resonate and compete with other conceptualizations, as exhibited by an early EES milestone—Massimo Pigliucci and Gerd Müller's *Extended Evolutionary Synthesis* compendium of 2010.

The advent of novel extensions to the synthesis and consequent alterations to basic assumptions and structural dimensions should come as no surprise in consideration of the consistent transformational character of evolutionary theory, as expressed by Godfrey-Smith: "The idea of an extension of Darwinism beyond its original domain is almost as old as Darwinism itself" (Godfrey-Smith 2009, 18). Laland echoes Godfrey-Smith (Laland et al. 2014, 162):

> **Charles Darwin conceived of evolution by natural selection without knowing that genes exist. Now mainstream evolutionary theory has come to focus almost exclusively on genetic inheritance and processes that change gene frequencies. … Yet new data pouring out of adjacent fields are starting to undermine this narrow stance. An alternative vision of evolution is beginning to crystallize, in which the processes by which organisms grow and develop are recognized as causes of evolution. … In essence, this synthesis maintains that important drivers of evolution, ones that cannot be reduced to genes, must be woven into the very fabric of evolutionary theory.**

The EES is an expanded conceptual and explanatory framework enabling evolutionary biologists and philosophers to think in sync with rapidly progressing research programs while making space for new explanatory approaches to the processes researched. The chief proponents of a revised and expanded synthesis are especially alive to over 80 years of impressive progress in biology, including processes which have been either overlooked or explicitly excluded by the MS, and to emphasize the need to integrate novel processes and problems, for “while such progress is undeniable, it does not imply that the underlying conceptual framework allows evolutionary biologists to make the most out of progress in biology and other fields” (Ibid.). The milestone of formalization produced by evolutionary biologist Laland and his multidisciplinary company (2015) state that “the EES is not just an extension of the MS but a distinctively different framework for understanding evolution, which, alongside more traditional perspectives, can be put to service constructively within the field” (Ibid. 3). The structural components of *constructive development* and *reciprocal causation* enable the EES to encounter the ineluctable exigency to include now empirically obvious drivers of evolution, which non-trivially influence patterns of selection and variation. Inclusive inheritance, developmental bias, developmental plasticity, and niche construction are causal catchalls, “problem agendas,” conceptualizing the multiplicity of processes responsible for evolutionary change across phylogenetic and ontogenetic scales (Hennig 1966, Gould 2001, Oyama 2000).

There is a tendency to see a canonized theoretic construct (or synthesis) as conservative in relation to new constructs, which are taken to be initiating revisions of revolutionary consequence. The relation between the MS and the EES differentially repeats this tendency, and in many respects the EES advocates new assumptions, structures, and predictions, which conflict with, and in some cases outright overturn those of the MS, but the revisionary aspects of the EES are not of a radical character in relation to the empirical exigencies, the problem agendas, emerging in the 80 years of salient science since the original congealment of the MS. The inferences, explanations, and theories constitutive of the MS have grown increasingly radical in light of the data driving a new synthesis. Strict commitments to gradualism, to natural selection as the preeminent—perhaps even exclusive—causal force of modification, to exclusively genetic inheritance, and so on, are far too reductive for the explanatory targets, or problem agendas, produced by the disciplinary multiplicity. The exclusive approach of the MS exhibits a genuine attempt to identify the key evolutionary processes, the causal roots, of the tree of life in parsimonious fashion fit for empirical tractability and testability, but the exclusion, or deflation, of the evolutionary significance of the problem agendas motivating a Twenty-first Century synthesis is clearly unwarranted. The inclusivity of the EES is not uncritical open-mindedness, nor a brazen breakage of the principle of parsimony. The open-endedness of the problematic structuring of the EES exhibits the nature of open-ended causal models it aims to express. Expressive simplicity is a noble aim in science, in philosophy of science, and philosophy of nature, but degrees of simplicity vary relative to the target of explanation or conceptualization.

1.3 Unidirectional Versus Reciprocal Causality

The causal assumptions of the EES mark its deepest divergence from the MS. The constructive processes given evolutionary credence by the EES force a major revision of the causal nature of natural selection amid a multiplicity of relevantly influential factors. The multidimensional and multimodal causal multiplicity of the EES is attentive to a variety of temporal rates and processes of change—redolent yet irreducible to the multiplicity of tempos and modes explicated by the great paleontologists of the 20th Century (Simpson 1944, Eldredge and Gould 1972, Fitch and Ayala 1995). The rate and direction of evolutionary change are determined by a multiplicity of causally efficacious developmental processes operating through developmentally generated transgenerational biases and the construction of transgenerational niches, which interact with the especially powerful process of natural selection. he novel concept not only critiques this classic causal structure but further transforms the alternative causal structure proposed by the EES—that of *reciprocal causation*: “the idea that developing organisms are not solely products, but are also causes, of evolution…process A is a cause of process B and, subsequently, process B is a cause of process A, with this feedback potentially repeated in causal chains" (Laland et al 2015). Reciprocal causation is acknowledged in evolutionary biology in some domains, e.g. coevolution, niche selection, sexual selection, and frequency-dependent selection, but the EES considers reciprocal causalities nearly universal in evolutionary and developmental systems.

Prior to constructing an alternative approach to evolutionary causality, the critical efforts of the EES target evolutionary biologist and pioneering philosopher of biology Ernst Mayr's very influential dichotomy between *proximate* and *ultimate* causation (Mayr 1989, 1993). The dichotomy distinguishes between causes that explain evolutionary processes (ultimate) and causes that explain merely the outcomes of evolutionary processes (proximate). Commitment to the distinction forms an assumption about the nature of evolutionary time and change maintaining that evolution occurs in a unidirectional path of determination in which microevolutionary causes extrapolate macroevolutionary effects. The causal assumptions of the MS thus involve one-directional arrows, monolithic modality, and an invariant tempo of change. Genetic inheritance is the lone director of evolutionary change and thus developmental processes are relegated to a relatively negligible (or trivial) status. These assumptions reduce an organism's development, the construction of its cultural lifeways, e.g. social norms and institutions, its niche constructive capacities, etc., to a causally *proximate*—thus *ultimately* trivial—evolutionary role. The dichotomy has effectively functioned in this manner to bias the MS toward *causal minimalism* (Lewins 2000, Laland et al. 2011, Godfrey-Smith 2014). This family of minimalist causal commitments explicitly exclude a multiplicity of purportedly nontrivial processes from the construction of evolutionary theory. The fidelity between the contemporary state of data and the *causal pluralism* or *causal multiplicity* central to the EES is the strongest appeal of the synthesis, but still suffers from underconceptualization.

The EES problematizes the already vexed causal assumptions and inferences constituting the MS (Laland et al. 2011). Prior to constructing an alternative approach to evolutionary causality, their critical efforts target evolutionary biologist and pioneering philosopher of biology Ernst Mayr's very influential dichotomy between proximate and ultimate causation (Mayr 1989, 1993). The dichotomy distinguishes causes that explain evolutionary processes (ultimate) and causes that explain merely the outcomes of evolutionary processes (proximate). Ultimate explanations are assemblages of inferences attempting to determine the selective histories of traits and why they have been selected rather than other traits. Proximate explanations are *functional* explanations attempting to determine "an immediate, mechanical influence on a trait," for example, "the influence on day length on the concentration of a hormone in a bird's brain" (Laland et al. 2011, 1512). A disciplinary distinction follows from the explanatory distinction: *evolutionary* biologists pursue ultimate causes while *functional* biologists target proximate causes. The explanatory and concomitant disciplinary distinctions are fundamentally determined in their difference by the unidirectional causality operating between them.

The unidirectional causality of the MS is mechanistically explained by natural selection as the programmer of organisms. Functional biologists construct proximate explanations by attending to the "decoding of the programmed information contained in the DNA code" (Mayr 1961, 1502). Evolutionary biologists construct ultimate explanations by attending to "the laws that control the changes in these codes from generation to generation" (Ibid.). The arrow of evolutionary causality is totally determined by the gene frequencies of genotypes, thus precluding causal relations of reciprocity between ultimate and proximate factors, as succinctly articulated in the following summation of the evolutionary process, formulated by Mayr some 35 years later, evincing his firm dedication to the dichotomous framework: "All of the directions, controls and constraints of the developmental machinery are laid down in the blueprint of the

DNA genotype as instructions or potentialities" (Mayr 1984, 126). The gene-centered conceptualizations of evolution fundamental to the MS assumptions and structural components, which purportedly hold the promise of specifying natural selection acting on particle-like genes, are highly influential instances of idealization "not only in obvious ways, [as] in their treatment of mating systems and the like, but [also] in their treatment of genes themselves" (GodfreySmith 2014, 98). In contrast with the particulate conceptualization, Godfrey-Smith avows the increasingly prevalent perspective that "genomes are more organized objects, and their contrasting partition into genes more artificial than the classic models suppose" (Ibid. 99).

The proximate-ultimate dichotomy functions for the MS as a fundamental justification of the theoretical and practical separation of evolutionary biology and developmental biology. Gene-centrism is a radically reductive assumption of the MS, what Godfrey-Smith calls an *idealization* (2014), which functions in an efficient manner to reinforce this separation. Evolutionary process is idealized as change in gene frequencies. Developmental processes are indirect shapers of gene frequencies. The causal forces of developmental processes are reckoned too weak to warrant the status of "difference-makers" in the evolutionary scheme of things (Godfrey-Smith 2009). The evolutionary biologist is concerned with them only (1) as products of genetic processes and patterns of stability and change, (2) as negligibly causal influences on variation, or (3) as *constraints* on evolution. Developmental constraints are causes of the *absence* of evolution in a given population, perhaps explaining why phenotypes are not functioning properly or optimally.

Mayr's paradigm example, bird migration, purports to double as justification of the dichotomy. The physiological functionality of migration can be explained with success without an evolutionary understanding of the ultimate causes of migration. The mechanical explanation is not only capable of independence from ultimate causes, functional biologists ought to methodologically suspend ultimate causes of migration, which should be deferred to evolutionary biologists—the latter likewise ought to actively suspend proximate causes from their explanatory efforts. An ultimate explanation of the evolved migratory behavior of birds targets its descent from flightless dinosaurs as a responsive assemblage of traits to the autonomous and relatively stable pressures of their environments. As with bird physiology, proximate causal processes of the environment, such as the relation between the earth's tilt and seasonal patterns, would be suspended from the ultimate explanation.

Mayr's dichotomous strategy was spurred by controversy between ultimate and proximate accounts of bird migration stemming from their confusion concerning these two distinctive, yet not competing, approaches to explaining bird migration. Mayr contended that the heated debate would be disentangled and the tension between the distinct approaches deflated once all biologists recognized that ultimate explanations encountering why birds migrate as they do and proximate explanations of the mechanics of such migration compliment rather than conflict with one another. Mayr's reconciliatory effort led gradually to the generalization of the dichotomy, which has undoubtedly played an impressively productive role in biology and the philosophy of biology—a subdiscipline of the philosophy of science Mayr helped to establish— by clarifying debates redolent of the bird migration case, and by methodologically orienting biological subdisciplines and adjacent disciplines. "Mayr's account of causation has become so ingrained among biologists that few appreciate that it is a convention. That both biologists and philosophers have taken issue with Mayr's stance, and that there are other ways of describing causation" (Laland et al. 2011, 1512). Ironically, the convention meant to overcome conflict between distinct explanatory approaches through their complementarity has since become the source of the most fundamental and the most contentious debates of contemporary biological theory and practice. The many disciplines dedicated to constructing an EES have developed the most incisive and concerted deconstruction of the convention. They have also constructed in its wake the most compelling model of evolutionary and developmental causality.

In a groundbreaking article for the growth of the EES, "Cause and Effect in Biology Revisited: Is Mayr's Proximate-Ultimate Dichotomy Still Useful?" (2011), evolutionary biologist Kevin Laland, philosopher Kim Sterelny, biological anthropologist John Odling-Smee, along with biologists William Hoppitt and Tobias Uller affirm the endurable quality of Mayr's convention: "Mayr's concern that proximate and ultimate explanations should not be regarded as alternatives remains entirely valid today and is an important and useful heuristic that applies broadly across biological disciplines" (Ibid. 1515). Nevertheless, the convention has proven problematic and ultimately untenable in its sweeping application "because it builds on an incorrect view of development that fails to address the origin of characters and ignores the fact that proximate mechanisms contribute to the dynamics of selection" (Ibid.). The convention untenably functions as a general conceptual framework, calling for a new framework: "reciprocal causation may now prove more useful than a unidirectional characterization, because it is better placed to accommodate the insights of developmentally minded evolutionists" (Ibid.). The EES axes of *reciprocal causation* and *constructive development* are gradually explicated in contrasting fashion from the unidirectional causation of the MS and its preclusion of proximate causation as a source of evolutionary change and stability.

The article thus takes issue with the case of bird migration serving as a widely generalizable example of ultimate and proximate causation in biology. The case is convenient for Mayr's purposes, for the causal assemblage of bird migration can be parsed with simplicity according to the proximate-ultimate distinction. Furthermore, the unidirectional causality operating between the ultimate evolutionary causes of bird migration and the proximate developmental causes of bird physiology attempts to clarify the nature of the relation between the explanatory modes, but the

EES censures such a widespread theoretical and practical move based on the incontrovertible evidence accrued against the dichotomy and its unidirectional causality since Mayr's work. The trenchant assumption of unidirectional causality in the MS is parallel to the unconscious opportunism of philosophy and science's subordination of time to measurement (per Poincare), and more deeply to movement (per Deleuze). The assumption that all developmental processes are subordinated to evolutionary processes by unidirectional causal vectors is like the multiplicity of temporality being subordinated to movement by chronometric synchronization, rendering its rate invariant, its directionality merely linear, and its quality monolithic. Both cases of unconscious opportunism are practically motivated by the scientific progress made by rendering causality and temporality invariables, constants to be assumed, not questioned, for as Poincare points out, the stakes are too high and the reconstruction efforts too daunting for scientists and philosophers to unsettle these methodological conventions (see Chapter 2). Just as the temporal subordination is protectively embodied in chronometric technologies, so too is the unconscious bias toward unidirectional causation protectively embodied in the proximate-ultimate dichotomy, with its methodological instructions and disciplinary divisions. The unconscious opportunism of the MS is reprised in the final section of the chapter.

The causal assumptions of the EES mark its deepest divergence from the MS. The advocates of the EES encourage "open discussion of the fundamental causes of evolutionary" (Laland et al. 2011, 163). The multidirectional and multimodal causal multiplicity of the EES is alive to a variety of temporal processes and rates of change—redolent yet irreducible to paleontological frameworks, including an increasing profusion of tempos and modes (Simpson 1944, Eldredge and Gould 1972, Fitch and Ayala 1995). The predominantly gene-centric approach of the MS cannot accommodate the multiplicity of nontrivial causes of evolutionary processes. The constructive processes given evolutionary credence by the EES force a major revision of the causal processes involved in the structure of the MS. The new structure of the former configures a multitude of causal influences beyond genetic variation and natural selection. The EES constructs a framework of reciprocal causality and constructive development openly encountering the ineluctable exigency to accommodate now empirically obvious drivers of evolution, which non-trivially influence selection and drift at the genetic level. Inclusive inheritance, developmental bias, developmental plasticity, and niche construction are causal catchalls conceptualizing the multiplicity of processes responsible for evolutionary change across phylogenetic and ontogenetic scales (Hennig 1966, Gould 2001, Oyama 2000).

The unidirectional causal relation implied in the case of bird migration conflicts with the many cases of reciprocal causality robustly researched by disciplines salient to evolutionary biology, whereby developmental processes figure nontrivially into ultimate explanations. The MS acknowledges reciprocal causality in special cases—habitat selection, sexual selection, coevolution, and frequency-dependent selection. The EES affirms "reciprocal causation to be a typical, perhaps even universal, feature of evolving and developmental systems, characterizing both the developmental origin of phenotypic variation and its evolution in response to changeable features of its environment" (Laland et al. 2015, 7). The EES acknowledgement and embrace of the ubiquitous multiplicity of reciprocal causal processes in nature relegates cases of sharp distinction and unidirectional relation between ultimate and proximate causes to the margins. The EES correlatively determines unidirectional selection to be "a special case of reciprocal causation where feedback is negligible" (Ibid. 1515).

1.4 Core Assumptions of the Modern Synthesis

The core assumptions of classical evolutionary theory coalesced by the MS and of the more contemporary coalescence of the EES involve temporal presuppositions, which are lightly brushed in the present chapter. They are developed in greater depth and sharper specificity throughout the thesis. The following theoretical lineaments are generally characteristic of the MS, with the obligatory caveat that the MS is comprised of a multiplicity of theorists and scientists with nuanced, not infrequently conflictual, commitments. Thus the following series of core assumptions sweeps across the differences of this multiplicity for provisionally practical purposes.

(1) Natural selection is the preeminent mechanism generating evolutionary change.

(2) Microevolutionary processes extrapolate macroevolutionary patterns of change.

(3) Evolution is defined as change in gene frequencies.

(4) Genetic inheritance is the only system of transgenerational transmission relevant to evolutionary explanation.

(5) Genetic variation is random.

(6) Evolutionary change actualizes at a gradual pace.

Natural selection is the preeminent mechanism generating evolutionary change. The MS fervently affirms the mechanism of natural selection as the primary sequence of processes filtering and shaping the grand multiplicity of life forms of earth. The natural selection of adaptive traits of organisms enable them to survive and reproduce in relation to the selection pressures of their respective environments. Developmental or ontogenetic mechanisms during a particular generation of organisms are biologically important processes to research, yet they are distinct from evolutionary concerns, for they are ultimately trivial processes that do not produce changes in future generations. The genetical theory of natural selection is first rigorously conceptualized, and eventually adopted by the MS, in the work of Ronald Fischer. The following fundamental theorem is the centerpiece of the very influential *Genetical Theory of Natural Selection* (Fischer 1930): "The rate of increase of fitness of any organism is equal to its additive genetic variance in fitness at that time." Selection produces modifications in gene frequency at a gradual rate. Fischer and his colleagues surmised that evolutionary changes led inevitably to increased fitness through the incremental formation of adaptations.

The causal assumptions operating at the core of the MS *reduce* an organism's development, the construction of its cultural lifeways, e.g. social norms and institutions, its niche constructive capacities, etc., to a causally *proximate*—thus *ultimately* trivial—evolutionary role (Mayr 1984, Laland et al. 2011). Genetic inheritance is the lone director of evolutionary change and thus developmental processes are relegated to a relatively negligible (or trivial) status.

Mayr's dichotomy between ultimate evolutionary and proximate developmental causality (addressed at length in Chapter 3), adopted by the MS in spades, entails an evolutionary brand of *causal minimalism* (Lewins 2000, Godfrey-Smith 2014). These assumptions imply that mutations and recombinations are generated by random (or adaptation-neutral) genetic variation within and between populations across *temporally invariant generations* of individuals (problematized in Chapter 3). Changes in gene frequency eventualize *incrementally*, at a gradual pace, and *unidirectionally* from randomly generated genotypes to adaptive phenotypes through the powerful mechanism of natural selection. These changes can be recorded and assessed upon an invariant evolutionary timeline. Natural selection on random genetic mutation, interacting with drift and gene flow, cause evolutionary changes in the gene frequencies of populations, detectable in effect through observation of the phenotypic changes of individuals, which actualize at a steady pace (Wray 2011). Exclusion of causal efficacy during the lives of organisms in conjunction with the relative stability, or the gradual change, of ecological conditions preclude nontrivially variable rates of evolutionary change. The strict restriction of nontrivial mechanisms of evolutionary stabilization and modification to natural selection entails one-directional arrows, monolithic modality, and an invariant tempo of change. The restrictive causality of natural selection, with its necessary and sufficient conditions, reduce evolutionary time to movement.

Microevolutionary processes extrapolate macroevolutionary patterns of change. The consistently gradual rate of evolutionary change from one generation to the next is determined by the slow speed at which the microevolutionary processes of genetic variation and natural selection produce macroevolutionary traits and states with adaptive value. The stabilization and modification of macro-traits and states are measured according to chronometrically biased methods and technologies, which neutralize variation in the tempo and mode of evolutionary change by subordinating time and process to movement and mechanism. Microevolutionary movements are captured and sequenced. Evolutionary inferences drawn from genetic sequences purport to explain observed macro-traits and states, all-the-while uncritically and opportunistically assuming a time scale determined by a measurable form of time. Thus the temporally invariant measurements of genetic sequences provide explanatory support for proposed mechanisms, functions, and traits observable at macroevolutionary strata.

Developmental processes are relegated to a relatively negligible status as drivers of evolutionary change, because ontogeny occurs as a result of genetic change, so the vectors of linear differentiation and cycles of repetition prevent critical consideration of evolutionary time.

Evolution is defined as change in gene frequencies. Natural selection, random genetic mutation, drift, and gene flow determine changes in gene frequencies, generating evolutionary stability and change in the heritable traits of populations. MS explanations of evolutionary change in a population's genetic composition are causally restricted to processes acting directly on gene frequencies. Gene-centrism reduces an organism's developmental processes to a nontrivial evolutionary status, for these processes are not direct actors upon gene frequencies. Organismic stability and change ostensibly due to developmental bias and phenotypic plasticity are either explicable as products of natural selection at the genetic level, merely proximate causal influences upon variation and hence evolutionarily negligible, or otherwise considered *constraints* (Sterelny and Griffiths 1999, Laland et al., 2011). The latter are causes not of evolutionary stabilization or modification but rather produce the *absence* of evolution—why it has *not* actualized in a given context. Constraints might also explain why phenotypes are less than optimal in a given circumstance. Gene-centrism restricts evolutionary time to the scale of genetic causal interaction, which is chronometrically sequenced. Observable evolutionary changes resultant of gene frequency changes at the strata of organisms and populations become irrelevant to the determination of evolutionary temporality.

Genetic inheritance is the sole system of transgenerational transmission relevant to evolutionary explanation. The standard definition of biological inheritance turns on transmission—the process of transferring a unit of selection to future generations, or the state of a unit having been transferred. The central assumption of the MS maintains that chromosomal genes are the sole basis of heredity, the sufficient causal individual differences, the *differencemakers* (Godfrey-Smith 2009, 2014). The MS strictly defines inheritance as the transmission of genes—the units of selection—from parents to their offspring, passing on traits and trait propensities to children, and indirectly to their grandchildren, and so on. The transmission of DNA alone explains similarity between parents and offspring. Genetic programs are often metaphorically referred to as blueprints, recipes, instructions, etc. Phenotypic variants, states, and stabilized traits are thus pre-screened and predetermined in time. Arrows of evolutionary temporality are unidirectionally predetermined by cycles of genetic programming. Genetic inheritance directs evolutionary change in a preeminently powerful and pervasive fashion such that developmental traits are solely determined by naturally selected genetic variants apt to produce heritable traits fit for optimal development. The MS commitment to exclusively genetic inheritance explicitly precludes a multiplicity of potentially nontrivial difference-makers in the evolutionary process. These commitments form an assumption about the nature of evolutionary time and change maintaining that evolution occurs in a unidirectional path of determination in which microevolutionary causes extrapolate macroevolutionary effects.

Genetic variation is random. The MS claims that mutations and recombinations are generated by random genetic variation within and between populations across temporally invariant generations of organisms. Developmental processes of bias and plasticity play no causal role in affecting let alone producing genetic variation. Directional vectors of increased fitness are causally unrelated to the random directions in which mutations eventualize. Phenotypic variation is not biased in directionality by genetic variation, but rather by the transgenerational selection of randomly generated genetic variants. Genetic variation is thus irrelevant in itself to the nature of evolutionary time. The processes of natural selection acting on random genetic variation forms the arrows and cycles of evolution.

Evolutionary change actualizes at a gradual pace. The consistently gradual rate of evolutionary change across millennia of generations is determined by the slow and steady speed at which random genetic variants are selected for transgenerational inheritance according to the viability of these variants stabilizing traits with adaptive value. The gradual pace is due to the incremental nature of evolutionary process. Evolutionary stability and modification is measured by chronometrically biased methods and technologies, which effectively neutralize variation in tempo and mode of change by subordinating time and process to movement and mechanism. Changes to phenotypic traits actualize incrementally. Large-scale changes through mutations is highly improbable due to the maladaptive traits—pleiotropy, whereby single genes produce multiple outcomes. The Marfan gene is the classic case of pleiotropy, producing extra-long fingers and toes. Time is not at issue for the MS, it is not an exigent problem, for the linear directionality flows at a relatively invariant pace, stable enough to measure evolutionary stability and change upon a timeline determined by normal temporal recording methods endemic to our culture. Variations in the temporal nature of evolutionary process are trivial.

1.5 Core Assumptions of the Extended Synthesis

The EES is a transformative revision and robust expansion of the MS in the light of over 75 years of impressive progress since the advent of the latter. The EES "is not just an extension of the MS but a distinctively different framework for understanding evolution, which, alongside more traditional perspectives, can be put to service constructively within the field" (Laland et al. 2015, section 1). The EES revisions and extensions to the tacit and explicit MS lineaments are all-too-briefly brushed in this section, and ought to be accompanied by the same obligatory caveat. There are relatively distinctive "teams" of theorists and scientists researching under the EES banner that differ in nuanced ways. The conceptual work of Laland and company is "motivated by the belief that there is heuristic value in specifying its conceptual structure in sufficient detail for the EES to serve as an alternative 'ecological-developmental perspective', to be deployed alongside more traditional standpoints to stimulate useful work. We believe that a plurality of perspectives in science is healthy, as it encourages consideration of a greater diversity of hypotheses, and instigates empirical research, including the investigation of new phenomena" (Laland et al. 2015, section 6). Some EES theorists and scientists are more radical in their proposed reforms than others. Some synthesizers advocate or emphasis the importance of certain extensions over others. There are also relatively trivial terminological differences and differences in organization. Nevertheless, there is a clear thread weaving them together, which the core assumptions brushed below attempt to articulate. These revisions and expansions correspond with MS assumptions touched upon above.

1.) **Organisms construct and are constructed by selective and developmental environments through reciprocal causality.**

2.) **Macroevolutionary patterns of change are explained by a multiplicity of evolutionary processes.**

3.) **Evolution is defined as transgenerational change in the distribution of heritable traits of a population.**

4.) **Genes are not the only means of inheritance, which extends to other transgenerational transmission systems.**

5.) **Some phenotypic variation is biased by non-random genetic variation.**

6.) **The speed of evolutionary change is variable.**

Organisms construct and are constructed by selective and developmental environments through reciprocal causality. Richard Lewontin (1983) insisted for decades that genes, organisms, and environments formed a causal network of underappreciated complexity. Empirical support for such a complex network has accumulated at a rapid pace since Lewontin's pioneering efforts. The EES emphasis on *constructive development* and *reciprocal causation* has encountered such complexity with impressive conceptual innovations. The causal assumptions of the EES mark its deepest divergence from the MS. The advocates of the EES encourage "open discussion of the fundamental causes of evolutionary" (Laland et al. 2015, 163). The EES constructs a causal framework openly encountering the ineluctable exigency to accommodate now empirically obvious drivers of evolution, which non-trivially influence selection and drift at the genetic level. Inclusive inheritance, developmental bias, developmental plasticity, and niche construction are causal catchalls conceptualizing the multiplicity of processes responsible for evolutionary change across phylogenetic and ontogenetic scales (Hennig 1966, Gould 2001, Oyama 2000). The constructive processes given evolutionary credence by the EES force a major revision of the causal nature of natural selection amid a multiplicity of future traits of populations. EES configures a multitude of causal influencers of nontrivial difference-makers beyond genetic variation and natural selection. The multidimensional and multimodal causal multiplicity of the EES is attentive to a variety of temporal rates and processes of change— redolent yet irreducible to the multiplicity of tempos and modes explicated by the great paleontologists of the 20th Century (Simpson 1944, Eldredge and Gould 1972, Fitch and Ayala 1995).

Natural selection is not the sole process driving evolutionary repetition and difference. The rate and direction of evolutionary change are determined by a multiplicity of causally efficacious developmental processes operating through developmentally generated transgenerational biases and the construction of transgenerational niches, which interact with the especially powerful process of natural selection. The concept of *reciprocal causation* proposes that "developing organisms are not solely products, but are also causes, of evolution…process A is a cause of process B and, subsequently, process B is a cause of process A, with this feedback potentially repeated in causal chains" (Laland et al 2015). Reciprocal causation is acknowledged in evolutionary biology in some domains, e.g. coevolution, niche selection, sexual selection, and frequency-dependent selection, but the EES considers reciprocal causalities nearly universal in evolutionary and developmental systems. Reciprocal causality is analyzed at length and problematized in Chapter 3.

Niche construction is "the process whereby the metabolism, activities and choices of organisms modify or stabilize environmental states, and thereby affect selection acting on themselves and other species" (Laland et al 2015, 4). Niche construction generates gradual and rapid directional changes in organisms and populations over time undeniably impacting their evolutionary pathways (Olding-Smee, Laland, Feldman 2003). It does so in several ways: (1) by "imposing systematic bias on the selection pressures they generate" (Laland et al. 2015, 4) through non-random modification of environmental conditions; (2) through transgenerational ecological inheritance; (3) when acquired characters modify selective environments; and (4) through various physical, social, cultural, and epistemic enhancements to organism-environment complementarity. The accrual of environmental modification—to soil composition, atmospherics, ocean states, etc.—precipitated by niche constructive processes can generate downstream developmental effects on descendant organisms, what the EES calls *ecological inheritance* (Ibid.). If a constructed feature of a niche achieves stability through high-fidelity and high-bandwidth in a population over the course of many generations it becomes comparable to genomic factors in its capacity to shape future evolution. Constructive development and niche construction problematize the unidirectionality and linearity of evolutionary arrows and the invariant temporal scale upon which the MS interprets and measures evolutionary cycles. The nature of evolutionary time becomes a complex multiplicity.

Macroevolutionary patterns of change are explained by a multiplicity of evolutionary processes. Developmental bias and niche construction are two macroevolutionary processes affecting macroevolutionary *and* microevolutionary patterns of stability and change. In the former case, ecological inheritance via niche construction, for instance, is capable of changing "the niches of other species in an ecosystem and in so doing lead to direct or diffuse coevolution, including via intermediate abiota, with potentially profound impacts on stability and dynamics of ecosystems on both micro- and macro-evolutionary timescales" (Laland et al. 2015, 4, OldingSmee, Laland, Feldman 2003, Erwin 2008). Causation thus flows forward as well as backward through autocatalytic feedback loops between micro- and macroevolutionary scales (Henrich 2015). The causal interaction between these scales imply temporal patterns irreducible to merely linear and invariant evolutionary temporality.

Evolution is defined as transgenerational change in the distribution of heritable traits of a population. The organism-centered redefinition of evolution broadens and deepens the nature of evolutionary process, emphatically rejecting the reduction of evolution's direction to selection on random genetic variation alone. The EES considers "the genome as a sub-system of the cell" (Laland et al. 2015, 6), and the cell as sub-systems of parts and processes of organisms. An organism can neither be reduced to genomic nor phenotypic factors, but is rather self-assembled through a multiplicity of interdependent sources. In accord with the axes of the EES— constructive development and reciprocal causation—a major predication of the EES is that "organisms will sometimes have the potential to develop well-integrated, functional variants when they encounter new conditions, which contrasts with the traditional assumption of no relationship between adaptive demand and the supply of phenotypic variation" (Laland et al. 2015, 8). Developmental bias and plasticity facilitate adaptive phenotypic variation by modifying selective environments, such that heritable traits are partially precipitated by organisms. Organisms themselves and the evolutionary dynamics between organisms, populations, genomes, and environments espouse a temporal multiplicity.

Genes are not the only means of inheritance, which extends to other transgenerational transmission systems. Nontrivial evolutionary inheritance is not restricted to the genetic transmission of DNA from parents to offspring (Cavalli-Sforza and Feldman 1981). Multiple mechanisms of transmission contribute to heredity, for parents also transmit developmental resources enabling the reconstruction of developmental niches (Jablonka and Lamb 2014). Transmission of such resources occurs consistently throughout the developmental phases of an organism's life, the span of which obviously varies in duration across different species, and across different subspecies, but generally begins at conception and ends when offspring become independent from parental influence. These parentally transmitted resources include (1) components of the egg; (2) post-fertilization resources, such as hormones; (3) maternal and paternal care; (4) parental modification of biotic and abiotic features of environments; and (5) symbiont inheritance through germ cells (or through infection) from the mother. Beyond developmental transmission from parents to offspring, inheritance occurs through horizontal and vertical social transmission, ubiquitous not only in vertebrate but also invertebrate populations (Hoppitt and Laland 2013). Social transmission has the capacity to catalyze population divergence and may initiate speciation events. The more inclusive EES conceptualization of heredity claims that "inheritance can occur from germ cell to germ cell, from germ cell to soma, from soma to soma, and from soma to soma via external environment" (Laland et al 2015, 4). Extra-genetic inheritance systems bias the expression and retention of phenotypes induced by physiological, ecological, social, and cultural environments. Epigenetic, physiological and ecological inheritance systems are also nontrivial influencers of evolutionary change and stasis (Jablonka and Lamb 2014). Empirical support for and theoretical modeling of social and cultural systems of transgenerational transmission have mounted since the turning of the century, and have been gradually accepted by evolutionary disciplines. All of these additional contributors to heredity are considered by most proponents of the EES to produce important evolutionary effects. These non-genetic inheritance systems can "bias the expression and retention of environmentally induced phenotypes, thereby influencing the rate and direction of evolution (Laland et al. 2015, 4, Badyaev 2009). The inclusivity of heredity variously advocated by EES theorists entails a multiplicity of arrows and cycles, challenging the standard assumption of incremental graduation and linear directionality.

Some phenotypic variation is biased by non-random genetic variation. The EES is committed to the proposal that variation is more predictable than the MS assumes (Pigliucci and Müller 2010). It also proposes that external selection pressures are less powerful than previously thought. Evolutionary-developmental biology (Evo-devo) has robustly demonstrated through decades of empirical research that "phenotypic variation often involves changes in gene regulatory machinery that alters the timing, location, amount or type of gene product" (Laland et al 2015, 3).

In other words, phenotypic variation is capable through developmental processes of biasing future genotypic outcomes—the nonrandom numbers of fingers, toes, limbs, and vertebrae are class examples. Developmental bias is capable of stabilizing and selecting certain phenotypic states over rather than others, thus enabling *facilitated variation*, "a mechanistic explanation for how small, genetic changes can sometimes elicit substantial, nonrandom, wellintegrated and apparently adaptive innovations in the phenotype" (Ibid, Kirchner and Gerhart 2010). Facilitated variation is assembled to the more established concept of *chance variation*, a concept which has undergone many internal variation. These concepts are reconfigured under the rubric of *evolutionary contingency* in Chapter 5 (Gould 2002, Plotnitksy 2004).

Plasticity has become a major target of empirical examination and theoretical modelling across a multiplicity of biological organization. Developmental or phenotypic plasticity in the context of evolutionary biology is "the capacity of an organism to change its phenotype in response to the environment" (Laland et al. 2015, 3). It is not only a phenotype's capacity to adapt to novel environmental pressures, but also contributes to what the EES calls *evolvability*, the transgenerational capacity of biological lineages to become more adept at adaptive evolution in relation to the advent of environmental novelty, because phenotypic plasticity is not just an evolutionary consequence, it is also a cause of phenotypic evolution. Phenotypic plasticity facilitates (1) transgenerational stabilization of novel environments; (2) affects the fidelity and bandwidth of population connectivity; (3) affects gene flow; (4) influences the temporal and spatial stabilization and modification of phenotypic variation in selection; and (5) is capable of increasing "the chance of adaptive peak shifts, radiations and speciation events" (Ibid.). *Phenotypic accommodation* and *genetic accommodation* are concepts the EES creates to explain the evolutionary efficacy of plasticity. The former refers to "the mutual and often functional adjustment of parts of an organism during development that typically does not involve genetic mutation" (Ibid. 3-4, West-Eberhard 2003). Phenotypic accommodation promotes the latter when "environmentally induced phenotypes are subsequently stabilized and fine-tuned across generations by selection of standing genetic variation, previously cryptic genetic variation or newly arising mutations" (Ibid. 4, Baldwin 1902). Phenotypic plasticity thus interacts with the mechanism of natural selection, not only nontrivially, but crucially, in determining which genetic variants will be selected to produce phenotypic variants.

The temporal assumption implicit in these empirically driven insights into developmental bias and plasticity is that reciprocal causal interaction between phenotypes and genotypes varies the rate at which evolutionary and developmental changes occur at these strata of the evolutionary process. More specifically, genetic accommodation is apt to produce rapid adaptation in the face of the advent of rapid environmental novelty, while the latter induces the selection of new phenotypes. Developmental bias and plasticity therefore make the task of tracking the temporality of evolutionary stabilization and modification of genotypes and phenotypes evermore challenging, as the rate of evolution is not only variable but also both linear and nonlinear in direction due to the interaction between evolutionary and developmental scales.

The speed of evolutionary change is variable. Characteristic of the naturalist perspective, Darwin marvels at the grand diversity of lifeways on earth, alive to differences in organismic structure, differences in expressions of these structures, and other differences in observed repetitions, patterns, or habits. Darwin does not opportunistically exclude apparent aberrations, or ostensive singularities, but rather cultivates perplexity in relation to them, including their modes and tempos as problems pertinent to evolutionary inquiry. Darwin acknowledges rate variability, but holds fast to the postulate that evolutionary change and preservation generally actualize at a gradual pace relative to deep time. "Gradualism may represent the most central conviction residing both within and behind all Darwin's thought," writes Gould. "Gradualism far antedates natural selection among his guiding concerns, and casts a far wider net over his choice of subjects for study" (Gould 2002, 148). The temporal multiplicity of rate is acknowledged as a nontrivial target of explanation but when stepping back and appreciating the deep historical patterns of change and preservation, an inference to graduation appears clear and compelling as a general rule, or heuristic. The gradualist assumption is of course convenient to Darwin's argument for natural selection as the preeminent causal force, but this is an insufficient counter to the assumption, which after all, strikes one as quite sensible. The greater challenge comes from the accumulation of research indicating significant variability in rate, direction-determining accelerations and decelerations, the drastic changes caused by catastrophic events, and the consequent problematization and eventual assumption of rate variability by the EES—a major revision of the MS. The EES ultimately repeats the gradualist eclipse of deep evolutionary time, even while it explicitly affirms variation in rate.

1.6 The Temporal Problematization of Evolutionary Synthesis

> *Looking back, I think it was more difficult to see what the problems were than to solve them.*
>
> – Charles Darwin, writing to Charles Lyell, September 20, 1859.

Godfrey-Smith (2009, 2014) draws an instructive distinction between *abstractions* and *idealizations* in evolutionary explanations. Abstraction understood in a commonsense fashion is the inevitable consequence of the human incapacity to account for everything. Abstract simplifications exclude certain explanatory exigencies for pragmatic purposes in favor of other factors for the sake of capturing key processes. Abstraction acutely alive to its potential for fallacious generalization, abstraction humble to its intrinsic limitation, is *productive simplification*. Theories composed of *deliberate* simplifications are idealized constructions, which "involve imagining things to be simpler than they really are" (Godfrey-Smith 2014, 98). It might provisionally be said that while abstractions are in a sense inevitable, idealizations are theoretical choices. Perhaps the most common simplifications in the history of evolutionary theory are summaries of *natural selection*. These summaries have normally attempted to simultaneously account for both the *causal problem* of how natural selection occurs—the problem of determining the necessary and sufficient conditions of evolution eventualizing through the hypothesized mechanism—and the *constitutive problem* of determining the conceptual components constructing the hypothesized mechanism as a force of evolutionary change. The gene-centered conceptualizations of evolution fundamental to the MS assumptions and structural components, which purportedly hold the promise of specifying natural selection acting on particle-like genes, are highly influential instances of idealization "not only in obvious ways, [as] in their treatment of mating systems and the like, but [also] in their treatment of genes themselves" (Godfrey-Smith 2014, 98). In contrast with the particulate conceptualization, Godfrey-Smith avows the increasingly prevalent perspective that "genomes are more organized objects, and their contrasting partition into genes more artificial than the classic models suppose" (Ibid. 99). The stratigraphic causal roles played by genes are problematized in the present chapter though constructively conceptualized in Chapter 5.

The long-term intention of many evolutionary theorists, including those associated with the EES especially, is to eventually explain evolutionary processes and patterns without idealizing—"Ideally, there would be no idealization" (Godfrey-Smith 2014, 24). Expressive simplicity is a noble aim in science, in philosophy of science, and philosophy of nature, but degrees of simplicity vary relative to the target of explanation or conceptualization. Albert Einstein succinctly expresses the aim, redolent of Occam's razor: "Everything should be made as simple as possible, but not simpler" (Einstein 1977). The EES problems demand concepts that are as simple as possible, but not as simple as the MS. The EES exhibits its problematic approach to the aim by building *continuous variation* into its components. *Stratigraphic time* conceptualizes the continuous variation of these "causal catchalls," unencumbered by the traditional trappings of causal logic as applied to evolutionary problems, especially its deterministic idealization of novelty. The stratigraphic temporality of evolutionary contingency explicated in the present chapter attempts to tackle this task.

The strictly gradual rate of transgenerational change attributed in these idealizations of evolutionary time and causality is determined by the slow speed at which genetic variation and natural selection through differential reproduction produce traits with adaptive value. The change is measured according to chronometrically biased methods and technologies, which neutralize variation in the temporal modes and differential scales of evolutionary modification and stabilization by subordinating time and process to movement and mechanism. Microevolutionary movements are captured and sequenced. Evolutionary inferences drawn from the genetic sequences assume a time scale determined by a measurable form of time. The temporally invariant measurements of microevolutionary movements are used as explanatory tools to suggest evolutionary mechanisms apt to determine macroevolutionary changes. The core Darwinian assumption of gradualism is addressed in Chapter 2.

CHAPTER 2. **DEEP TIME: THE FORGOTTEN FRONTIER**

Chapter 2 problematizes evolutionary temporality, arguing for the return of *deep time* as a problem of profound importance to understanding the history of life. Evolutionary theory has relinquished the problem of time in acquiescence to antiquated assumptions about the nature of time and its relation to evolutionary process, consequently entrenching tacit idealizations of evolutionary time and causality. The gradualist solution to the problem of evolutionary time has operated with preeminence in evolutionary thought since Charles Darwin's rationalist reception of the geological concept of deep time (1859). The rational quest of geology to reconcile arrows and cycles of time is marked by increasingly rigorous and systematic solutions to the problem of deep time (Hutton 1788, Lyell 1830, Gould 1987). The rationalist reconciliations increasingly eclipse the depth of the problem of geological time through circumscriptions of its multiplicity and insensibility in a hierarchy of causal relations. It is at the origin of evolutionary theory that the quest to render deep time rational culminates in *the gradualist solution*, an offspring of the deep time problem, not to mention a necessary condition for the preeminent operation of a rational mechanism of modification (natural selection). The rationality of gradual causal movement through deep time resonates with the rationality of natural selection as a preeminent force of modification and stasis in evolutionary lineages across *successive* and *discrete* generations.

Darwin purports to render "the insensible intermediacy" of natural selection sensible by reducing evolutionary time to empirically tractable and repeatable sequences. Darwin's gradualism illegitimately reduces evolutionary temporality to the slow, small, incremental, and sequentially ordered stages of these sequences. Lyell's rationalist geology, the rationalist philosophy of Leibniz, and the rationalist botany of Linnaeus pump the heart of Darwin's gradualist idealizations, emblematically expressed in an instructive motif of the *Origin*, an aphoristic principle avowedly important to Leibniz and Linnaeus: *Natura non facit saltum* (nature does not proceed by leaps). Darwin's rationalist concepts of evolutionary causality and temporality lead inferentially to *universal gradualism*, which is unwarranted in lieu of sensibility of modal and temporal intermediaries of evolution. The great challenge to the contemporary dominance of universal gradualism is the accumulation of research indicating significant variability in rate, resulting in the assumption of temporal multiplicity in contemporary syntheses (Laland et al. 2015). Adoption of the inferential generalization of gradual change to all evolution is due to *unconscious opportunism* (Poincaré 1907), to the stubborn power of *convention*, codified habit of evolutionary thought (Deleuze 1994), which ignores or denies compelling empirical confirmation of the irreducibility of evolutionary time to evolutionary process.

2.1 The Discovery of Deep Time

As thought digs increasingly deeper into the ebbs and flows of the earth, the forms of time and space become increasingly variable, and the human grasp on the "grandeur of life" (Darwin 1859) slips into humility, as evinced by the geological discovery of *deep time* (Lyell 1830, McPhee 1980, Gould 2001). Stephen Jay Gould goes so far as to argue that "the discovery of time was so central, so sweet, and so provocative, that we cannot hope to match its import again" (Gould 1987, 17). The advent of the concept is due to generations of observation and scientifically motivated inference, clashing with commonplace biases of anthropocentrism, assuming humankind the prized creature of the cosmos. The giant geological discovery of deep time shrinks humankind to a small segment, a miniscule slice, a mere sliver of time at the end of earth's awesome age. The humbling concept renders our species a tiny tree in the forest of life's history, not even a day-old infant born to our 4.54 billion year old parent planet.

Pondering the angular unconformities of strata at Scotland's Siccar Point, mathematician John Playfair (1748-1819) exclaimed to his friend and colleague, James Hutton (1726-1797)—the inventor of the deep time concept—that "the mind seemed to grow giddy by looking so far into the abyss of time" (Playfair 1805). Gazing nearly 200 years later into the depths of earth's temporal abyss, Gould attests to such giddiness, insisting that the "incomprehensible immensity" of deep time is grasped not in number but only in the gut: "An abstract, intellectual understanding of deep time comes easily enough—I know how many zeroes to place after the 10 when I mean billions. Getting it into the gut is quite another matter. Deep time is so alien that we can really only comprehend it as a metaphor" (Gould 1987, 3). The alien concept is so hard to comprehend, so beyond our everyday mode of thought and action, that it perplexes us perhaps as profoundly today as it did its pioneers. The heart of the present effort holds fast to the immensity and humility of deep time, immensity and humility motivating 21st Century evolutionary biologists and philosophers of nature to suspend the no doubt unique and impactful but perhaps disproportionately represented duration of humankind as the prime example of evolutionary process. The rationalist eclipse of the problem catalyzed by Darwin's concept of evolutionary time, *gradualism*, and hardened into a core assumption of the MS, already percolates at the advent of the concept of deep time.

Hutton created the concept in *Theory of the Earth* (1795) after decades of geological observation and interpretation. Hutton's masterpiece may have been lost to history if not for his aforementioned friend, John Playfair, whose cogent and compelling prose in *Illustrations of the Huttonian Theory of the Earth* (1802) popularized deep time and its evidence. Hutton's two breakthrough geological discoveries leading to the concept's formation call attention to *cyclic* processes of sedimentation. Hutton first observes that granite is igneous—rock solidified by magma or lava—indicating its uplifting and restorative forces. Hutton's observation purportedly nullifies the notion of an inevitably erosive earth over time, evincing an endlessly recycling earth instead. The second observation serves as the most direct evidence of the profundity of earth's temporal depth. Hutton acutely observed episodes of restoration between cycles of uplift and erosion, now canonically called *unconformities*—the boundaries between the uplift and erosion cycles of touching rock strata composed at different times. "An unconformity is a fossil surface of erosion," as defined by Gould, "a gap in time separating two episodes in the formation of rocks" (Gould 1987, 62). These unconformities indicate the periodic discontinuity of sediment deposition, an indication counter to the commonplace assumption of brief and unilinear decay—the historical arrow of erosion, as it were. Hutton's injection of restoration into geologic process lifts up eroded topographies thus interpreting its temporality as unlimited in its *cyclic* capacities for restoration. Hutton's inferences lead him to conceptualize the earth as a self-renewing machine of endless repetition, cycling through three stages: (1) The decaying topography of the earth washes via soil into the oceans; (2) Ocean basins become home to these deposits, which form horizontal strata that build up to a critical mass whereby the lower levels of sediment are moved by the pressure generated when the strata cross a sufficient threshold of heat; (3) Smoldering sediments at the lower levels are expanded and elevated by magmas "with amazing force" (Hutton 1988, 266), lifting land to become new continents while new oceans arise in other areas of the earth over old continents. Hutton's machinic earth is an endlessly repeating cycle of erosion, deposition, assembly, and restoration. Hutton deduces deep time from the circular churning of the earth machine. What is peculiarly fascinating about Hutton's discovery of deep time is that the concept is not inferred from observational induction. Deep time serves as the key ingredient in an *a priori* argument for the cyclic nature of the final and efficient causality of the earth. *Theory of the Earth* purports to be a *rational* theory of the earth, for the nature of the terrestrial machine's cyclicity and deep temporality is established prior to observational confirmation in the field, allegedly by logical necessity. Understanding the lineaments of this work is important because the rationalization of the earth in Hutton's mechanistic theory is a force of great influence on Darwin's rationalist commitment to gradualism in close connection with the causal mechanism of natural selection.

Using the tools of Aristotelian causal reasoning, Hutton builds a conceptual machine of efficiently operative mechanisms. In hindsight Hutton's innovative arguments clearly idealize deep time "*by imposing upon the earth the most rigid and uncompromising version of time's cycle ever developed by a geologist*" (Gould 1987, 78), as Gould emphatically concludes, by illegitimately applying Aristotelian logic to the observed temporality of earth. Hutton derives two a priori causal concepts of imagined simplicity: (1) the *final cause* of soil restoration enabling agriculture and life despite the erosion of topographies, and (2) the *efficient causality* of the machinic earth's recycling mechanisms. Hutton's work played a major role in the formation of the geological method, called *uniformitarianism*. Uniformitarianism is committed to the principle that the earth's past becomes clarified and specified through present observation—that "the present is the key to the past"— rather than through an ancient religious text of the past, such as the bible, the authority of which alone has the capacity, claims the catastrophist, of telling us of the past, present, and even the future of life on earth. Uniformitarianism maintains that natural processes and laws at work in contemporary observations function as these processes and laws did in the past. Thus the past conditions of the earth are uniform with present conditions of the earth. The present holds the key to discovering the past as a consequence of (1) the gradual nature of terrestrial change, and (2) the cyclic nature of machine earth's deep temporality. Hutton's idiosyncratic application of Aristotelian causal reasoning primes Darwin's manifold methodology of historical inference. In a limited sense, it could be said that Darwin transforms the abstract idealization of Hutton's giant machine into the abstract simplification of the machine conceptualized as *natural selection*. The topic resurfaces later in the present chapter and again in Chapter 5, where Darwin's inferential methods are problematized by work in the physical, life, and earth sciences.

Before he digs into the work of Hutton, Playfield, and others of the same ilk, young Darwin is significantly influenced by his collegiate teacher, Adam Sedgwick (1785-1873), a controversial founder of modern geology. Darwin poetically praises Sedgwick's brilliant contribution to the piecing together of the puzzle of geological time: "What a capital hand is Sedgewick for drawing large cheques upon the Bank of Time!" (Darwin 1832). As a priest, Sedgwick's geological orientation is naturally theologically influenced, but his work severely criticizes *scriptural geology*, a heterogeneous group of mostly 19th Century geologists insistent upon literalistic biblical exegesis as the primary method of geological interpretation. Sedgwick scorns the group for proposing "a deformed progeny of heretical and fantastical conclusions, by which sober philosophy has been put to open shame" (Sedgwick 1830, 310), and further that scriptural geology has "committed the folly and SIN of dogmatizing…sinn[ing] against plain sense… [and] of writing mischievous nonsense" (Sedgwick 1934, 148-153). Contrary to many religious contemporaries, he did not contend that the earth was 6,000 years young, but rather that its age surely exceeded our feeble grasp. Nevertheless, Sedgwick is a fervent proponent of natural theology, a lens through which he sees the formation of the earth as an effect of catastrophic causal events, notably Noah's flood. His geological interpretation is known as *catastrophism*, which is oriented by the assumption that turbulent events of rapid punctuation formed the earth (principally those chronicled in the book of Genesis). Catastrophic geologists typically appeal to the authority of biblical testament, an appeal to the past for insight into present terrestrial conditions, dismissing present observation as a point of access to the past.

Biblical appeal is not, however, a necessary condition for the geological school of catastrophism. Sedgwick was heavily influenced by the catastrophism of Georges Cuvier (1769-1832), a famous exception to the rule. The uniformitarian assumption of gradual terrestrial formation guiding geological inference sharply contrasts with the assumptions and methods of catastrophism, a contrast problematized in the fourth section.

While Sedgwick's skeptical attitude toward naïve scriptural approaches surely imparts to Darwin a critical capacity to challenge conformity to a trending theory, and while the teacher's acknowledgement of the depth of terrestrial temporality surely imbues his student with an appreciation of deep time, Darwin is ultimately uncompelled by catastrophism, opting instead for a version of the uniformitarian approach cultivated by Hutton and Charles Lyell (1797-1875). Voyaging aboard the Beagle, Darwin maintained consistent correspondence with Sedgwick, but his attention focused fastidiously and enthusiastically on Lyell's *Principles of Geology: being an attempt to explain the former changes of the Earth's surface, by reference to causes now in operation* (1830-1833)—the subtitle is a clear allusion to its uniformitarian orientation. Lyell rigorously refines Hutton's uniformitarian orientation. His masterpiece is more than a textbook of pseudo-objectivity, as some geologists have naively contended, more than a three-volume compendium of canonical information, for it forms a coherent argument for a grand vision of time's cyclic nature and of the nature of geologic change within the context of time's cycle. *Principles of Geology* is arguably the founding document of modern geology, and many contemporary geologists and paleontologists attest to this claim (Gould 1987, 101).

Much of Lyell's work matures as he studies the strata of Mount Etna, observing *gradual* changes from stratum to stratum over time. Lyell stratigraphically tracks patterns of sedimentation, especially fossil deposits, to ultimately prove the earth older than 6,000 years. Lyell enhances Hutton's concept of deep time, more robustly and incisively establishing it as a far more viable geological principle than the catastrophic account of earth's genesis. "The discovery of deep time, in this version," Gould enthusiastically exclaims, "becomes one of history's greatest triumphs of observation and objectivity over preconception and irrationalism" (Gould 1987, 6). Lyell's version is part and parcel of a methodological and substantive argument for the efficacy of four axes of *uniformity*: (1) The *uniformity of law*, in which natural laws are spatially and temporally constant. "The present is the key to the past" is defended as a viable methodological principle, as assumptions appealing to invariant natural laws provide a necessary warrant for the geologist to extend inductive inference deep into an unobservable past—a warrant acknowledged and analyzed by John Stuart Mill (1806-1873) in *A System of Logic* (1981); (2) According to the *uniformity of process*, the geologist is methodologically required to abstain from positing an unknown or extinct cause for a past process resultant of an observable process in the present—a principle known as *actualism*, maintaining that what is actual is what is *present* rather than the more substantive claim that what is actual is what is *real*. Gould refers to philosopher Nelson Goodman's work on scientific methodology, praising this principle as one of *simplicity*: "don't invent extra, fancy, or unknown causes, however plausible in logic, if available processes suffice" (Gould 1987, 120). Tangentially, one is begged to wonder to what extent Hutton's *a priori* argument for the deep cyclic time of the earth machine violates the second principle of uniformity in Lyell's eyes. Hutton egregiously violates the principle in Gould's eyes , among other rigid and overreaching theoretical violations; (3) The *uniformity of rate* postulates that geologic change is typically a slow and steady process—a principle now known as *gradualism* in evolutionary biology. Macroscale states and processes of the earth are incrementally built by the accrual of changes over a vast timeline. Contrary to catastrophism, major events of geologic change occur only local scales and only rarely. Lyell censures catastrophism as utterly unintelligible due to its anti-empirical methodology. Lyell replaces catastrophic causation with gradual causation; and (4) The *uniformity of state* postulates that the ostensible processes of the earth in the present are continuous with past terrestrial processes, taking a step beyond the uniformity of natural laws and of rates of change by claiming that the geologist is warranted in using the terrestrial order of contemporary states to infer past orderings of states. The claim of this principle hinges on the supposition that change is continuous, which is not to overreach in claiming that it is progressive, as Gould articulates: "Change is not only stately and evenly distributed throughout space and time; the history of our earth also follows no vector of progress in any inexorable direction" (Gould 1987, 123).

Sedgwick surely played a significant role in launching Darwin toward the geologically informed theory of "descent with modification," but there is no doubt that the uniformitarian approaches and conceptualizations of deep time developed by Hutton, Playfair, and Lyell played far more direct and formative roles. Darwin's teacher vehemently recoiled from *On the Origin of Species*. Sedgwick read the work with "more pain than pleasure," censuring many claims as "utterly false and grievously mischievous" in their "desertion" of "the true method of induction" (Sedgwick 1859). Darwin's methods of historical inference appeared unwarranted to him: "Many of your wide conclusions are based upon assumptions which can neither be proved nor disproved. Why then express them in the language and arrangements of philosophical induction?" The theologically motivated geologist opposed Darwin's proposal of a causal mechanism—natural selection—which Sedgwick thought should be renamed "development," determined by the causal power of God, whom "acts for the good of His creatures." Sedgwick continues his opposition with the claim that "He also acts by laws which we can study and comprehend—Acting by law, and under what is called final cause, comprehends…your whole principle." His criticism was even harsher in correspondence with others: "It repudiates all reasoning from final causes; and seems to shut the door on any view (however feeble) of the God of Nature as manifested in His works. From first to last it is a dish of rank materialism cleverly cooked and served up" (Sedgwick 1860). Sedgwick was right about the innovatively nonteleological approach of Darwin's methodology for drawing historical inferences. Chapter 5 emphasizes and examines the crucial role of the exclusion of final causes, and more subtle forms of teleological reasoning, in the causal assumptions of Darwin's theory and those that followed in his wake.

Darwin visits Lyell in 1860 to share his theory of evolution via natural selection. Lyell's response to Darwin's masterpiece is more sympathetic, though not without its reservations, ultimately finding the theory unconvincing. It takes him a half-decade to accept the very fact of evolution, of the shared history of life, and even longer to very minimally concede to the mechanism of natural selection. Lyell's resistance results from the theory's challenge to the fourth principle of his method, that of the uniformity of stately change, which denies progression. Lyell worried that the overturning of the fourth principle with an admittance of progression would cause the other three principles to collapse. After six years of consideration, "once accumulating evidence had reluctantly forced him to accept the fact of progress in life's history" (Gould 1987, 171), Lyell minimally retreated, accepting progressive evolution as a fact, thus relinquishing the fourth principle because it nevertheless "permitted him to preserve all other meanings of uniformity" (Ibid). Ceding progressive directionality carried with it a concomitant relinquishment: his passionate dedication to time's cycle. While admitting of the historical vectors of evolutionary change, Lyell found in Darwin's work corroboration of the uniformities of law, process, and rate. Lyell's assent to Darwinian evolutionary theory is demonstrated in the 1866 revision of *Principles of Geology.* Vectors of directionality in evolutionary history only rarely imply progress. Lyell and other astute contemporaries encountering Darwin's theory are first among a long line of readers to assume such an implication, an indication that Darwin needed to more clearly and carefully express the suspension of valuations of progress or decline in the determination of evolutionary process and history.

The next section explicates and problematizes a dichotomy of temporal metaphors, *arrows* and *cycles*, which attempt to simplify the positions and assumptions of characteristic patterns of thought pertaining to geological and evolutionary temporality. These metaphors have been heavily influential, sometimes constraining evolutionary thought, sometimes potentiating evolutionary thought. The conflict between these longstanding metaphors cogently construes the evolution of the concept of *deep time*, and its impact on evolutionary theory, as readily attested by Darwin (1859). Gould's *Time's Arrow, Time's Cycle: Myth and Metaphor in the Discovery of Geological Time* (1987) meticulously explicates and explains the history of time in geology and evolutionary theory, arguing for reconciliation between the metaphors as a necessary condition for understanding evolutionary process. Gould makes the tacit problem of time in evolutionary theory accessible through the dichotomy, motivating the problem's exigency by critically acknowledging the need to reconcile arrows and cycles. Gould argues that such reconciliation has the potential of modeling the inextricable entwinement between the nature of time and evolutionary process, a theoretic construct that later becomes his *tiers of time* model (1985; 2002), a topic of the final section.

2.2 Rationalist Reconciliations of Arrows and Cycles of Time

Time is notoriously the most well understood and simultaneously the most ill understood topic of thought, as Augustine famously quipped in *On Genesis* (389) and in *The Confessions* (Book XI, 397): "What *is* time? If no one asks me, I know; if I want to explain it to a questioner, I do not know." Augustine accounted for time as (1) a creation of God and (2) a phenomenon of human consciousness. These axes of investigation preceded Augustine and would go on to puzzle questioners of time till today, but as physicists, geologists, philosophers, and other thinkers developed new approaches to the problem of time, these axes of investigation became bracketed, problematized, and in some cases altogether jettisoned. The geological concept of deep time is not the time of God nor of human consciousness, but rather of the earth. While time may have become less mystified since the medieval age of Augustine, the problem remains profoundly perplexing. While "times arrow and time's cycle may be too simple and too limited" (Gould 1987, 194), the arrow-cycle dichotomy assists in orienting provisional analysis and evaluation of the nuanced history of vexed relations between theories of time and theories of evolution, which are difficult but indispensable to discern. The "incomprehensible immensity" of deep time, suggests Gould, is impossible to capture through abstract intellection, and thus we must resort to metaphor and other figurative gestures, which help us step closer to the edge of the abyss of time, assist us in peering into and perhaps reeling in grains of intelligibility with our feeble nets. Gould rightly regards the dichotomy as highly instructive for "each of its poles captures a deep principle that human understanding of complex historical phenomena requires absolutely—while other favored dichotomies, like evolution versus creation, cannot be so fruitful because the ends don't balance, at least in the sense that for classical issues…one side is simply wrong, and therefore drops from intellectual interest, though not necessarily from political clout" (Ibid., 194). Gould's own reconciliation of the dichotomyous poles is critically assessed in section 5. Cyclic concepts of time have held sway throughout human history as the default temporal setting of our psychological habits, social norms, and cultural institutions, as articulated in Mircea Eliade's magisterial *The Myth of Eternal Return: Cosmos and History* (1954)—the subtitle of which alludes to time's cycle and time's arrow. The human lineage relentlessly recoiled from time's arrow and the implications of its vectors of novel change, resistant to the advent of difference, which challenges the attempts of societies to forecast and control the future. Eliade vividly portrays the terror these cultures experienced in the face of distinctively meaningful events, of the arrow of time charged with causal directional import. Terrorized by natural events, like inclement weather and conditions of famine, and by cultural events, like war and local dissention, social groups shirked from attributing directional meaning to irregular, unpredictable, and unstable events of novel change and difference over time. In reaction to such terror, cultures clung to the repetitious nature of time's cycle, sought refuge and protection in the pretensions of predictability, regularity, and unchanging permanence through endless circular immanence. Distinctive events and differences in the past, or of the present, were safely rendered meaningless in subordination to repeating cycles of necessity, forestalling the contingent history and future of time's arrow. The metric and material institutions of contemporary culture have ostensibly overcome the unintelligibility and terror Eliade illustrates. The contemporary ubiquity and power of time's arrow has rendered time's cycle so unfamiliar that we now must recover the basic principles of interpretation embodied by time's cycle (Gould 1987, 14). Eliade argues for contemporary culture's exigent need to embark on such a recovery, not for the sake of validating time's cycle, but rather for the sake of retrieving the circular temporal context from which time's arrow emerged. Gould's impressive explication and explanation of the geological discovery of deep time—through linear and circular temporality—eventually casts a clarion call for the reconciliation of time's arrow and time's cycle, aims to fulfill Eliade's insist retrieval of cyclic concepts.

It is not especially challenging to grasp why cyclical thinking about time was deeply entrenched in human psychology and society. The earliest observations of temporal patterns, and later of their measurement, were of earth's cycles in the context of the greater cosmos—patterns of change from day to night and from season to season, celestial constellation patterns in the night sky. These observations and measurements enabled cultures to construct schedules and calendars apt to organize personal, social, and cultural lifeways. Time-keeping became more rigorous and accurate via technologies such as sundials and eventually mechanical clocks. The advent of time in human history thus determines time as the observation and measurement of cyclic celestial and terrestrial movements. Cyclic temporality became sedimented in human psychology, social norms, and cultural institutions. Spiritual, religious, philosophical, and scientific traditions held tacit and explicit assumptions based in cyclic temporality. The circular bias of temporal immanence is also evinced at the start of modern physics in the mechanical dynamics of Isaac Newton (1642-1727), for instance—a thinker dedicated to motion's laws, and the necessity of their cyclic (or time-symmetrical) nature. Newton plays a crucial, if initially antagonistic, role in the development of deep time. Gould begins his exploration of deep time's discovery with Newton's friend, Thomas Burnet (1635-1715), a reverend and biblical literalist dubiously remembered as the "primal villain" of geology's initiation, and of the discovery of deep time, due to his scriptural orientation (Gould 1987, 22). Burnet and Newton exchanged many lengthy letters debating the genesis of the earth and the temporal nature of terrestrial life (1681). Burnet challenges Newton's firm commitment to the cyclic nature of time, arguing for the existence of an arrow of time within the context of time's cycle. Burnet's novel penchant to configure the geological gravity of time's arrow is developed in his major work, *The Sacred Theory of the Earth* (1726), which "embodies time's arrow at its grandest—a comprehensive riproaring narrative, a distinctive sequence of stages with a definite beginning a clear trajectory, and a particular end" (Gould 1987, 22). The reverend's motivation for inculcating a temporal arrow into time's cycles between past and future is due to the narrative structure of scripture. Narrative serves as Burnet's explanatory target for several reasons: (1) the natural tendency of human curiosity; (2) the dictates of reason; (3) the nature of divinity; and (4) the undeniable weight of history's impact on the earth and humankind.

As a theistic scientist, Burnet seeks a physics of natural causes explaining the biblical narrative of God's creation, ordained from the moment of genesis. God ordained the laws of nature in a fashion fitting to the history of terrestrially bound creatures, and in such a way that interventions are prevented. The natural laws of space and time are invariant, a commitment Burnet shares with Newton. Burnet's directional position commits him to a beginning extending historically through significant events of change, leading him to strongly deny, however, the Aristotelian notion of eternal circularity, of a changeless cycle of nature. As a forerunner to catastrophism, Burnet takes Noah's flood as the prime problem to explain, thus suspending explanation of the origin of terrestrial life. If he can find a viable explanation for such a catastrophic event through the invariant physical laws of nature his method could successfully explain every other creative event in history. The correspondence between Burnet and Newton intensifies when the latter denies the importance of the flood in the formation of terrestrial topography, suggesting rather that the earth was shaped from primeval chaos. Burnet vehemently disagrees with Newton's creation account, which proposes that earth's essential laws were formed at the very start, for it sacrifices extended historical vectors. Burnet holds fast to his rationalist methodology, featuring historical explanation in contradistinction to the immanent cyclicity of Newton's philosophy and physics of space and time. Burnet refuses to give up on the reconciliation of the arrow's narrative power and the cycle's immanent regularity, attempting to conjoin the natural science of Newton with scripture to narrate terrestrial history. Burnet reconciles the two by theorizing that "history turns as a set of cycles (time's cycle), but each repetition must be different (time's arrow), in order to make time intelligible by imparting direction to history" (Gould 1987, 58). Both Darwin and Gould maintain cyclic repetition in their theories but go much further than Burnet is willing to venture by embracing the irreducibly contingent forces of history as the foremost forces repeated (not identities or resemblances). The primacy of time's cycle in Burnet's theory precludes difference-making contingencies in the histories of organisms, for both God and nature forbid such purposeless temporal processes. The origination and distribution of organic traits are determined by *preformed purposes*. The preformist bias (as introduced above, and often alluded to below) primes geology's underdetermination of the efficacy of contingent factors, relegating their investigation and theoretical integration to the fringe of deep historical explanation, in subordination to orderly efficacy under mechanistic control.

The cyclic temporality of Hutton's earth machine orders events into nested sequences. Hutton's concept of geological time effectively strips the singularities of events of real efficacy, for "Hutton's world machine is Newton's cosmos read as repeating order through time" (Ibid., 78)—ironic considering the basic aim of geology, which is to discover and articulate the deeply historical nature of terrestrial change. Time's cycle renders distinct events causally insignificant. History becomes an only apparent surface of a never changing repetition of fundamentally present states of temporal immanence. "The vision of time's cycle enabled Hutton and Lyell to grasp deep time," Gould grants "but we couldn't mark units within this immensity until time's arrow of the fossil record established a criterion of uniqueness for each moment" (Ibid., 197). Burnet's fervent attempt to introduce time's arrow into time's cycle is therefore important to the history of geology and to the discovery of time's arrow. Under the influence of Darwin, Lyell would eventually concede an arrow of time, but like Burnet, he would subordinate its differential directionality to the repetitions of time's cycle. It is often uncritically assumed that the earth and life sciences have historically endorsed the commonsense notion of time's arrow—that temporally irreversible and unrepeatable sequences of *novel* events form the directions of deep time, that contingency plays a specially efficacious role in determining history—but either explicitly (as in Burnet, Hutton, Steno, and so on) or tacitly (as in Darwin, Fischer, Mayr, etc.), the earth and life sciences have subordinated *manifold modes of contingency* to a *unidirectional causal flow*, an idealized chronological succession called geological or evolutionary history. Even the work of Simpson, Eldredge, Gould, Lewontin, and other evolutionary life and earth scientists, which has admirably legitimized the efficacy of contingency, lack robust concepts of evolutionary contingency, let alone contingency as such (Simpson 1944, and especially 1953; Eldredge and Gould 1972; Gould and Lewontin 1979). The chapter turns now to important rationalist concepts of arrows and cycles preceding evolutionary theory.

2.3 The Gradualist Eclipse of Geological Time

Time's arrow is not introduced in full force until Darwin's theory of contingent history, "a quirky sequence of intricate, unique, unrepeatable events linked in a unidirectional chain of complex causes (and gobs of randomness) …" (Gould 1987, 59). While Burnet sought vectors of history in the perfections of organisms, history evinces itself to Darwin through imperfections, through the quirks of evolved structures. Darwin deemed the former a fool's errand, for evolved perfections of organismic structure hide the traces of their own formation. Darwin's concept of contingent history reconciles a genuine arrow of time with time's cycle. Repetitions in organismic structure through natural selection reconciles the latter with the substantial randomness of variation, with unpredictable vectors of novelty. Darwin's reconciliation is all too tacit, however, as Gould emphasizes. Darwin's lack of an explicit concept of evolutionary time alive to the discovery and historical development of the deep time concept is a lacking that continues through evolutionary syntheses to the present day.

The cycle-arrow dichotomy undoubtedly aided pioneers of deep time to think beyond the box about the origin and history of life on earth, of its repetitive patterns and vectors of difference, primarily with an eye to reconstructing the past but also looking forward to future repetition and difference. Gould makes the tacit problem of time in evolutionary theory accessible through the dichotomy, motivating the problem's exigency by critically acknowledging the need to reconcile arrows and cycles. In order for it to function fruitfully as a contemporary tool of analysis, evaluation, and creativity the metaphorical poles must be reconciled in a compelling fashion alive to current science and theory. There is "something deep in our tradition," insists Gould, which requires "both the arrow of historical uniqueness and the cycle of timeless immanence—and nature says yes to both" (Gould 1987, 200). Gould argues that such reconciliation has the potential of modeling the inextricable entwinement between the nature of time and evolutionary change, insisting that a successful reconciliation is a necessary condition for understanding the temporal nature of evolution, which is a necessary condition for understanding the nature of evolution itself (Ibid., 16).

The rational quest of geology to reconcile the arrows and cycles of deep time is marked by increasingly rigorous and systematic solutions to the problem of deep time. The rationalist reconciliations increasingly eclipse the depth of the problem of geological time, variously circumscribing its multiplicity and insensibility in a hierarchy of causal relations, which subordinate and effectively neutralize temporal relations (see Chapter 3). At the same time, the very existence of deep time is more robustly demonstrated by stratigraphic data, and increasingly accepted as fact. The growth of methodological rigor and inferential rationality in geology fostered the development of evolutionary theory. It is at the origin of evolutionary theory that the quest to render deep time rational culminates in *the gradualist solution*, an offspring of the deep time problem, not to mention a necessary condition for the preeminent operation of a rational mechanism of modification (natural selection). Due to the immense importance of Darwin's defense of natural selection, it is easy to overlook how most of the *Origin* is an exposition of gradualism. "Gradualism may represent the most central conviction residing both within and behind all Darwin's thought. … Gradualism far antedates natural selection among his guiding concerns, and casts a far wider net over his choice of subjects for study" (Gould 2002, 148; cf. Gould 1984). Darwin's gradualist conviction is motivated by its logical entailment, or necessary implication, in his "one long argument" (1859) for natural selection as the preeminent force of evolution, to be sure, but his "strong, even pugnacious, defense of strict gradualism" (Gould 2002, 151) belies Darwin's deep rationalism, the greater motivation for his gradualist conviction. Darwin's argument determines the temporal nature of evolution in accordance with "Lyell's conflation of gradualism with rationality itself" (Ibid), reducing time to evolutionary process, to causal relations ordered into sequences. Not only is time reduced to temporal modality, it is reduced to only one mode of time (succession). The rationality of gradual movement through deep time resonates with the rationality of natural selection as force capable of causally ordering evolutionary lineages across successive generations.

Lyell's rationalist geology, the rationalist philosophy of Leibniz, and the rationalist botany of Linnaeus pump the heart of Darwin's gradualist theory of evolution by natural selection, emblematically expressed in an instructive motif of the *Origin,* an aphoristic principle avowedly important to Leibniz and Linnaeus: *Natura non facit saltum* (nature does not proceed by leaps). Darwin does indeed conflate gradualism with rationality, assuming the temporality of evolutionary process to be sequentially ordered accordingly to classical causal logic: "As natural selection acts solely by accumulating slight, successive, favorable variations, it can produce no great or sudden modification; it can act only by very short and slow steps. Hence the canon of '*Natura non facit saltum*' … is on this theory simply intelligible" (Gould 2002, 471). Darwin's commitment to gradualism extends to the human desire to know itself, to know the mind, to know the origin and history of the human lineage, a desire allegedly only gradually satiated. In the sole statement about human evolution in the *Origin*, Darwin takes the opportunity to attest to the pervasive sway of gradualism: “Psychology will be based on a new foundation, that of the necessary acquirement of each mental power and capacity by graduation. Light will be thrown on the origin of man and his history” (Darwin 1859, 488).

The insensibility of intermediate steps of infinitesimally small changes problematizes empirical procedures and principles, in a way appropriate to the imperfections of the fossil record, to which Darwin frequently alludes. Darwin purports to render the insensible intermediacy of natural selection sensible by reducing evolutionary time to empirical intelligibility, but the inference to universal gradualism is unwarranted in lieu of sensible access to the modes and tempos of evolutionary process. The great challenge to gradualism comes from the accumulation of research indicating significant variability in rate—direction-determining accelerations and decelerations, the drastic changes caused by catastrophic events—resulting in the assumption of rate variability in the EES. Darwin’s gradualism illegitimately subordinates evolutionary temporality to slow, steady, small, sequentially ordered, and continuously flowing movements. The solution’s illegitimate eclipse of the problem belies the unwarranted commitments motivating and presupposing Darwin’s stringent doctrine of gradualism. Contextualization of these commitments clearly explain their illegitimacy. “Natural selection can only act by the preservation and accumulation of infinitesimally small inherited modifications” (Darwin 1859, 95). Natural selection would be relegated to an auxiliary force if punctuations of large variations were frequent. Selection sequentially orders accumulation to produce the parts of organisms. The slow and steady pace of change enables natural selection to superintend salient variants. Selection’s force has a relatively long operative duration, causally assembling sequences of variants favored for their viability as increments building adaptive characters. Selection becomes productive only when it has plenty of time, many generations, to impart direction to evolution.

Darwin does indeed conflate gradualism with rationality, assuming the temporality of evolutionary process to be sequentially ordered accordingly to classical causal logic: "As natural selection acts solely by accumulating slight, successive, favorable variations, it can produce no great or sudden modification; it can act only by very short and slow steps. Hence the canon of '*Natura non facit saltum*' … is on this theory simply intelligible" (Gould 2002, 471). Darwin purports to render the insensible intermediacy of natural selection sensible by reducing evolutionary time to empirical intelligibility, but the inference to universal gradualism is unwarranted in lieu of sensible access to the modes and tempos of evolutionary process. The great challenge to gradualism comes from the accumulation of research indicating significant variability in rate—direction-determining accelerations and decelerations, the drastic changes caused by catastrophic events—resulting in the assumption of rate variability in the EES. Darwin's gradualism illegitimately subordinates evolutionary temporality to slow, steady, small, sequentially ordered, and continuously flowing movements. The rationalist and cultural influences of Darwin's historical niche on his commitment to gradualism resonates with the physical commitments of classical mechanics, specifically with the assumption of the invariant passage of time—a Newtonian influence Darwin inherits from the geological lineage of Burnett, Hutton, Lyell, and others, but of course Darwin's reckoning of Newton is ultimately unique from his geological forerunners. Chapter 2 and Chapter 3 explicate the tacitly influential force of Newtonian science noticed not only in Darwin but before him in Kant, where the purportedly pure and empty form of time is unconsciously filled, and consequently compromised or contaminated, as it were, by Newtonian commitments.

The gradualism of the MS conflicts with two core paleontological observations: (1) the geologically abrupt advent of most species in the fossil record and (2) the fixation or stasis of most species for long durations of deep time. The paleontological determination of the temporal nature of evolutionary process problematizes the nexus of the MS. Darwin was alive to the various temporal patterns evinced in the nuanced histories of species expressed in the fossil record. The absence of gradual patterning in the evolution of species was not perceived as a threat, for Darwin's deep distrust of the fossil record is a strong motivation of his uniformitarian method of historical inference, which draws evolutionary inferences not from relics of the past but rather from contemporary products of evolution. The adaptive character of organismic parts bear the marks of its historical construction, the extensive trace of the intensive processes productive of the adaptation. The histories of lineages are explicable through the analysis of these adaptations. The adaptationist research program is logically attuned to the uniformitarian methodological approach to geological, paleontological, and evolutionary history wherein "the present is the key to the past." Causal inferences cannot be drawn with sufficient support from the faulty fossil record, but must be drawn rather from contemporary evolutionary products available to direct study. Causal sequences productive of present organisms must be inferred from the adaptive character of these organisms. Phenotypic variants are capable of directing the stabilization and modification of organisms and populations via developmental bias and plasticity, as well as though niche construction, occasionally precipitating relatively rapid rates of evolutionary change. Constructive development and niche construction contrast "with the classical emphasis on gradualism, which followed from the assumption that, to be adaptive, mutations must have small effects. What the historical rejection of saltationism overlooked was that mechanisms of developmental adjustment allow novel structures to be effectively integrated" (Laland et al. 2015, 9).

2.4 Methods of Historical Inference in Early Evolutionary Biology

Causal inferences are fundamental to evolutionary explanations. Unable to directly observe processes of the past, evolutionary science must draw causal inferences from an imperfect historical record, turning in recourse to contemporary biotic and abiotic variables, which are directly observable, and sometimes subject to experimental intervention. Causal processes of the past are inferred according to a more or less rigorous standard of "sufficient similarity" between directly observable causes in contemporary and experimental contexts and indirectly encountered causes of the past stratigraphically preserved in the paleobiological record. The imperfections of the fossil record Darwin deems potentially misleading and consequently detrimental to historical inference, opting instead for indirect yet abundant data from contemporary biotic and abiotic contexts. The introduction to the *Origin* suggests that sufficient confidence in evolution can be achieved by attending acutely to the contemporary conditions of life on earth, by "reflecting on the mutual affinities of organic beings, their embryological relations, their geographic distribution, geological succession, and other such facts" (Darwin 1859, 3). The problem of history and Darwin's methods of historical inference "…set the more general theme underlying both the establishment of evolution as a fact, and the defense of natural selection as its mechanism" (Gould 2002, 99). The present section examines Darwin's methods of historical inference and how they operate in Darwin's theory, the central causal force of which is of course the mechanism of natural selection. *Darwin's causal minimalism* primes evolutionary theory for 150 plus years of an assumption *of unidirectional causality*, fundamental to the structure and content of the MS, and rivaled in the 21st Century by the EES concept of reciprocal causality.

Darwin begins the final chapter of the *Origin* by retrospectively characterizing the work as "one long argument" (Darwin 1859, 459). Darwin argues for the very fact of evolution, and further for the fact and force of its focal mechanism, natural selection. The *Origin* is more subtly, yet just as importantly, a parsimonious yet nuanced argument for methodologically rigorous modes of historical inference from evolutionary processes and products (Gould 1986, Ghiselin 1969). Indirect empirical support for evolutionary history, as opposed to a creationist history, for instance, is imperfectly provided by the fossil record. Direct empirical support for evolutionary history is provided by contemporary biota and abiota. The problem of evolutionary history therefore confronts scientists and philosophers with two formidable challenges: (1) History hands us a stratigraphic paleobiological record chalk full of deficiencies, of breaks, discolorations, chips and dents, and other deformities due to the weathering of deep time; (2) Historical sequences and their causal relations elude standard scientific modes of observation, measurement, experimentation, inferential retrodiction and prediction due to their unique, unrepeatable, and contingent nature. The clear establishment and consistent adherence to heuristics of evolutionary inference are of critical importance due to the imperfect preservation of the former and the problematic depth of the latter. Darwin is just as philosophically motivated and oriented as preceding evolutionary theorists, but Darwin's dedication to drawing inferences and constructing theories that are tractable and testable, his scientific motivation and orientation, distinguish the *Origin* from forerunning efforts.

While Darwin's theory of evolution is popular for its application to the human organism, to *The Descent of Man* (1871), his argument in the *Origin* appeals to a copious cacophony of contemporary organisms to illustrate how inferences to evolution are methodologically drawn. The many modes of coral atoll formation concerned the budding naturalist aboard the Beagle (1842); the symbiotic fertilization assemblage between orchids and wasps (and other insects) attracted Darwin's inquisitive gaze (1862); as did *The Movement and Habit of Climbing Plants* (1875); *The Different Forms of Flowers on Plants of the Same Species* (1877); *The Power of Movement in Plants* (1880); soil formation cultivated by worms (1881), etc. The quantity and quality of data available to Darwin across this multiplicity of case studies varies, and thus they require a variety of inferential strategies. Gould parses "a fourfold continuum of methods for the inference of history," ordered according to decreasing data density (Gould 2002, 103-116):

> (1) *Uniformity* is in operation in Darwin's final book, on worms, wherein Darwin explains the topography and topsoil of England by "extrapolating the measured work of worms through all scales of time" (103). The geological method eventually emerging from Hutton's work is called *uniformitarianism*, which attempts to articulate inferences about the earth's past, its formation and changes, through present observation. Uniformitarianism is committed to the principle that the earth's past becomes clarified and specified through present observation—that "the present is the key to the past"—rather than through an ancient religious text of the past, such as the bible, the authority of which alone has the capacity, claims the catastrophist, of telling us of the past, present, and even the future of life on earth. Uniformitarianism maintains that natural processes and laws at work in contemporary observations function as these processes and laws did in the past. Thus the past conditions of the earth are uniform with present conditions of the earth. Hutton's uniformitarian heuristic is a major tenet of Darwin's manifold methodology of historical inference. Given ample evidence, an inferential extrapolation from direct observation of modes and rates of change in contemporary organisms may be effectuated.
>
> (2) *Sequencing* defines and orders ostensibly unrelated and independent configurations of organismic processes into phases of a single historical process. Unable to directly

observe configurational changes, they must be inferred as temporally sequenced products of a single successive process of change, an inferential procedure employed to explain the historical process of coral atoll formation, delineating three configurations of reefs as sequential stages of this one process (fringing reefs, then barrier reefs, and finally atolls).

(3) *Consilience* is a concept created by polymath William Whewell (1794-1866), which he characterized as a "jumping together" (Whewell 1840). Consilience refers to the apparent assemblage of a multiplicity of otherwise disparate consequences via one causal process, whereby concordance of the several variables involved could not otherwise be conceived. Causal inference of this kind establishes strength through persistent confirmation of the unique assemblage inferred. Darwin appeals to consilience to extract inferences from vast and various data accrued to explain why some plant taxa grow different kinds of flower formations on the same plant type. "In a sense," suggests Gould, "consilience defines the larger method underlying all Darwin's inference from historical records" (104). The inferential extrapolation strategies of uniformity and sequencing enable the reconstruction of historical successions of related events, movements, and organisms salient to evolutionary process. Challenged by far less information, the inferential strategy of consilience has only the configuration of a single state of affairs to base its historical conjecture.

(4) *Discordance* is the last resort of historical inference, when the density of available data is scant, when observation of variables provides insufficient information to warrant consilience. Darwin's methodological approach to such translucency takes heed of discordance between an organism and its contemporary circumstances, of the imperfections indicative of discordance between them. When imperfections are the

data driving inference of historical change, adaptive optimality in the contemporary context is ruled out, indicating a vestigial status in which a previously adaptive function has become atrophied or otherwise discordant in relation to current conditions. Darwin's inferences concerning the intricately adaptive history of orchids owes not to the prowess of optimal design, specially fit to face pressures of current conditions, but rather to makeshift contraption built of parts from ordinary flowers in symbiotic assemblage with insects—a heterogeneous yet adaptive assemblage of otherwise discordant organisms.

The mechanism of natural selection is well known as Darwin's most innovative, important, and influential historical inference. Darwin argues for the existence and force of natural selection as a logical entailment of three indisputable factual propositions: (1) The *superfecundity* of reproduction, whereby all kinds of organisms overproduce offspring, results in the likelihood that many offspring will not survive. Darwin's statement of superfecundity is developed in novel fashion and defended as fact in the early chapters of the *Origin*. (2) *Variation* is ubiquitously evident among all organisms, whose individual features are relatively unique. (3) Offspring *inherit* some variants. Even if the transmission processes of heredity are underdetermined, even utterly altogether undeterminable (as they seemed in Darwin's day), the fact of heredity is undeniable. Such a simple syllogistic abstraction of the mechanism is provisionally effective, yet ultimately quite weak in explanatory power, for it only establishes that natural selection works as a force of change in a population in the first place, that the mechanism is powerful enough to incrementally produce adaptive traits. To move through and beyond the simple expression is to enter "the guts of natural history," to problematize *how* natural selection works. The abstract argument alone only establishes *that* it works, though it "says nothing about the locus, the agency, the efficacy, or the range of selection in a domain—

the sciences of natural history—where all assessments of meaning rest upon such claims about mode, strength, and relative frequency, once the prior judgement or mere existence has been validated" (Gould 2002, 126).

Darwin not only claims at the causal core of the *Origin's* "one long argument" that natural selection actually exists and indeed influences the direction of evolution but also, and equally importantly, that natural selection is the primary driver of the arrow of evolution, the preeminent causal force determining evolutionary processes and products. The focal causal force plays more than a filtering role (as in de Vries 1901), eliminating unfit variants in favor of preserving fit variants for transgenerational transmission, natural selection plays a constructive role, producing fit relations between organisms, and between organisms and their niches. The paradox of Darwin's crucial constructive claim is that natural selection produces nothing directly. The constructive efficacy of the mechanism therefore requires reliably copious, smallscale, and undirected variation. Without a plenum of continuous variation, natural selection would have nothing to select. The constructive efficacy of the mechanism also requires the incremental actualization of "insensibly graded series" (Darwin 1859), the slow and steady accumulation, of organismic construction and modification. Lastly, the causal dynamics of the force of change must transgenerationally transmit reproductively successful characters with highbandwidth and high-fidelity. The direction-determining mechanism cannot produce anything by itself, so variation must be consistently plentiful, but variation must also be direction-neutral, "raw material," unbiased, ready, and able for the constructive operation of natural selection. If variation had intrinsic directional efficacy, natural selection would be relegated to an eliminative role in subordination to the causal force of large-scale mutations. At best, natural selection would be able to accelerate or decelerate change already underway under the directional determination of variation. The claim that variation is unrelated to vectors of adaptive change—the products of natural selection—is fundamental to Darwin's argument.

Natural selection works though competitive relations between individual organisms struggling for reproductive success. Darwin restricts causal efficacy to one stratum alone, the organismic stratum. Adaptive change is the central target of classical evolutionary science studying this stratum upon which selection acting on struggling organisms. Darwin argues that natural selection is not just an efficacious force, it is the *preeminent* force of evolution at all strata and scales, starting with the advent of initial biotic lineages through geologic time's grandeur of generations and cessations. Working incrementally through geologic time's multiplicity of modes and tempos, in continuous variation, natural selection functions as an efficacious causal force constructing sequences of organismic adaptation. The struggle produces at the microevolutionary strata the ordered sequences of ostensive adaptiveness observed at macroevolutionary strata. Despite Darwin's persistent denial that preeminence implies exclusivity, Darwin is persistently misinterpreted as claiming natural selection the sole mode of modification in evolutionary history. 13 years after the publication of the *Origin*, in the sixth edition, Darwin emphatically disputes this frequent misunderstanding (Darwin 1872, 395):

> **As my conclusions have lately been much misrepresented, and it has been stated that I attribute the modification of species exclusively to natural selection, I may be permitted to remark that in the first edition of this work, and subsequently, I placed in a most conspicuous position—namely at the close of the Introduction—the following words: "I am convinced that natural selection has been the main, but not the exclusive means of modification." This has been of no avail. Great is the power of steady misinterpretation.**

This power of steady misinterpretation exemplifies Monod's astute observation that the "…curious aspect of the theory of evolution is that everybody thinks he understands it. … While in fact very few people understand it, actually, as it stands, even as it stood when Darwin expressed it, and even less as we now may be able to understand it in biology" (Monod 1975, 12). Characteristic of the naturalist perspective, Darwin marvels at the grand diversity of lifeways on earth, alive to differences in organismic structure, differences in expressions of these structures, and other differences in observed repetitions, patterns, or habits. Darwin does not opportunistically exclude apparent aberrations, or ostensive singularities, but rather cultivates perplexity in relation to them, including their modes and tempos as problems pertinent to evolutionary inquiry. Darwin does not exclude means or modes of modification other than natural selection. He is happy to persuade readers that natural selection is the preeminent mode. A similar approach is taken with respect to the assumption of gradualism. Darwin acknowledges rate variability, but holds fast to the postulate that evolutionary change and preservation generally actualize at a gradual pace relative to deep time.

Darwin attests to the power of the problem of variation on evolutionary and developmental scales, readily admitting that "our ignorance of laws of variation is profound" (Darwin 1869, 67). The direction-determining mechanism cannot produce anything by itself, so variation must be consistently plentiful, but variation must also be direction-neutral, "raw material," unbiased, ready, and able for the constructive operation of natural selection. If variation had intrinsic directional efficacy, natural selection would be relegated to an eliminative role in subordination to the causal force of large-scale mutations. At best, natural selection would be able to accelerate or decelerate change already underway under the directional determination of variation. The claim that variation is unrelated to vectors of adaptive change—the products of natural selection—is fundamental to Darwin's argument.

Darwin's methods of historical inferences determine the causal nature of the relation between (1) copious, small, and undirected variation and (2) the efficacious operation of natural selection. The latter cannot function as the preeminent force of evolutionary without the direction-neutral, tiny, and prolific production of variants, for natural selection is not itself a producer of variants. Variation is thus an enabling condition of selection. Natural selection operates efficaciously by transforming variation within populations into fitness differences between populations. In order for natural selection to function as the preeminent causal force in evolutionary time Darwin must constrain the nature of variation in three ways that elevate adaptation as the central explanatory target: (1) Variation is a direction-neutral origin of raw material unable to cause evolutionary productivity by itself; (2) The insensible intermediacy of gradualism guarantees the constructive efficacy of natural selection as the preeminent cause of evolutionary change proceeding in small increments; (3) The direction-neutrality of variation and the constructive efficacy of natural selection make adaptation the primary inferential target of evolutionary research. Darwin's deep distrust of the fossil record is a strong motivation of his uniformitarian method of historical inference, which draws evolutionary inferences not from relics of the past but rather from contemporary products of evolution. To Darwin's delight, adaptation appears ubiquitous on earth: "…we see beautiful adaptations everywhere and in every part of the organic world" (Darwin 1859, 61). The insensibility of the intermediary processes constitutive of natural selection precludes direct observation of their causal dynamics, so the next best point of access to these processes are the primary products of the successive causal interactions productive of the spatial and temporal aspects of the adaptations in relation to environmental conditions. The adaptive character of organismic parts bear the marks of its historical construction, the extensive trace of the intensive processes productive of the adaptation. The histories of lineages are explicable through the analysis of these adaptations. The adaptationist research program is logically attuned to the uniformitarian methodological approach to geological, paleontological, and evolutionary history wherein "the present is the key to the past." Causal inferences cannot be drawn with sufficient support from the faulty fossil record, but must be drawn rather from contemporary evolutionary products available to direct study. Causal sequences productive of present organisms must be inferred from the adaptive character of these organisms.

2.5 Revivals of the Problem of Evolutionary Time

The temporal problematization of the extended evolutionary synthesis revives the problem of deep time through a philosophical concept, *stratigraphic* time. The geological concept of deep time was eclipsed by the idealization of Charles Darwin's concept of evolutionary time, *gradualism*. Considering the forerunning impetus of geology in the advent of evolutionary biology, and specifically the concept of deep time in the work of Darwin and other evolutionary trailblazers, one would think that a special place of explanatory depth would be given to the nature of time within evolutionary theory, and yet the nature of time has been neglected by classic and contemporary syntheses. There are few exceptions to this generalization. Appeal to the concept of time for the purpose of restructuring the framework of evolutionary theory was ventured by Niles Eldredge (1985b) and Gould (2002), avowedly in response to paleontologically studied temporal patterns in tension with assumptions of the MS, but with minimal impact on the whole of evolutionary theory. The second half of *The Structure of Evolutionary Theory*—Gould's "War and Peace of evolution" (Plotnitsky 2002), his "last will and testament" (Sterelny 2002)—culminates in a unique conceptualization of time as a coexistence of three tiers of evolutionary time interacting in a uniquely scaffolded fashion. The tiers of time theory is first floated in a programmatic article of 1985, "The paradox of the first tier: an agenda for paleobiology." The conceptual framework received minimal attention, in adverse relation to its ambition. The temporal tier theory has received even less attention since the publication of *The Structure of Evolutionary Theory*. Of the dozens of reviews written on the tome, few give more than passive mention of the innovative attempt to move "towards a revised and expanded evolutionary theory," initially surprising considering the temporal model's crucial role in constructing Gould's vision for "a new Modern Synthesis." Gould's pioneering attempts to "revise and expand" (2002, Part II) the MS suggest that proponents of the EES should be acutely attentive to the exigency of time, and evolutionary contingency, but the EES has yet to conceptualize and integrate the temporal nature of evolutionary process tacitly operative in the depths of its assumptions and extensions. Herein lies a major motivation of the dissertation, namely to conceptualize the lineaments of evolutionary process developed in the EES in the light of a cogent and compelling concept of evolutionary time.

Gould attempted to synthesize geology and paleontology with evolutionary biology and genetics through a concept of time. *The Structure of Evolutionary Theory* culminates in a unique conceptualization of time as a coexistence of three tiers of evolutionary time interacting in a uniquely scaffolded fashion. The tiers of time theory is first floated in a programmatic article of 1985, "The paradox of the first tier: an agenda for paleobiology." The conceptual agenda is undeniably innovative, and cogent, but if one were to judge its success based on the criterion of its reception by salient scientific and theoretical communities, the framework is a failure. Beyond the pithy reception, Gould's approach belies his constrained perspective on the nature of time. The tiers of time model construes the levels of evolutionary processes according to a concept of time subordinated to movement. Gould's innovative model would have benefitted from a deeper understanding of the history of the philosophy of time. The temporal lens of Gould's innovative *tiers of time* framework is instructive, however minimal its impact, and despite the unnecessary constraints of his conceptualization. Gould's constructive engagement with the problem of evolutionary time provides historical, geological, and theoretical preparation for the philosophical conceptualization of this problem. The advantages of the concept of stratigraphic time lie in part in its philosophical vantage on the edge of the Copernican turn in temporality

(Chapter 2), and its conceptualization of time's evolutionary modes and tempos according to active and passive syntheses (Chapter 6). Before mining classical and contemporary evolutionary syntheses for tacit and explicit arrows and cycles of temporality, it is important to briefly explicate the tiers of time framework, which Gould hoped a "revised and expanded synthesis" would take seriously. It will become readily apparent in sections 4 and 5 that they did not, and hence lack a concept of evolutionary time.

Gould's concept of *tiers* emphasizes differential interaction across three separable temporal scales of evolutionary process. The first tier is the microevolutionary level of individual organisms. The second tier is the macroevolutionary level of species, and the third tier is the level of mass extinctions, perhaps of entire fauna. Gould criticizes the Modern Synthesis for reductively rendering macroscales of temporal phenomena, processes we actually observe, as extrapolations from microevolutionary scales of struggle between individual organisms. Gould calls the incapacity of evolutionary theory to identify and specify the progressive arrow of time in life's history "the paradox of the first tier," the anti-reductive resolution of which turns on the nature of interaction between the tiers: "whatever accumulates at the first tier is sufficiently reversed, undone, or overridden by processes of the higher tiers" (Gould 1985, 1). Gould's prime examples are events of *punctuated equilibrium* (Eldredge and Gould 1972), the concept proposing that stabilized species persist in stasis for long stretches of time, and that interruptive events of evolutionary change happen rarely and rapidly, producing cladogenesis (events of branching speciation). Events of punctuated equilibrium at the second tier generates patterns of change in species unrelated to the adaptive fitness of organisms at the first tier, but nevertheless results in the ontogenetic structure of organisms. At the third tier, mass extinction events, "now recognized as more frequent, more rapid, more intense, and more different than we had imagined," may reverse, or utterly erase, accumulated traits at the second and first tiers. The action of the third tier on the second and first tiers, and the second tier upon the first, effectively radicalize Darwin’s introduction of contingent history, while giving credence to time’s cycle in the form of long periods of repetition, of *stasis* at the first and second tiers. Gould’s reconciliatory framework is reprised and criticized in the second half of the dissertation, where it is argued that the concept of stratigraphic time is a more effective conceptualization of the multiplicity of evolutionary interactions between time’s arrows and time’s cycles.

Chapter Three

CHAPTER 3. THE CHRONOMETRIC SUBORDINATION OF TIME TO MOVEMENT IN PHILOSOPHY, SCIENCE, AND SOCIETY

Chapter 3 critically argues that the subordination of evolutionary time to process is primed by the chronometrically facilitated subordination of time to movement, what mathematician, physicist, and philosopher of science Henri Poincaré (1854-1912) called an unconscious opportunism in philosophical and scientific thought. The genetically determined assumption of unidirectional causality in consensus syntheses of the past exemplifies these subordinations. Explication of the uncritical subordination of time to movement operative in philosophy and science enables evaluation of the problem of evolutionary time in its various subordinations to evolutionary process. Poincaré's problematization of the subordination, at least the reciprocal determination, of temporality to causality opens a philosophical door to a new conceptualization of their relations, beyond the seemingly inevitable supposition that time is reducible to causal succession—moving from ostensive antecedent to ostensive consequent. The question begged (petitio principii) by the problem, as acknowledged by Poincaré in the last sentence, is constructively engaged in the final two chapters, which attempt to respect causal thinking while conceptualizing evolutionary processes not according to causal laws but rather according to passive and active temporal syntheses (or modes of repetition), effectively delimiting causal thinking to a provisional conceptualization. The powerfully persistent perception of cause-effect relations ineluctably influences thought, and should be respected as such. The derivative status of time as defined in Aristotle's *Physics* is gradually reconfigured throughout the history of Western philosophical thought, from the Stoics through Neoplatonism into the Middle Ages, Descartes, Newton, and Leibniz, but takes a revolutionary turn in Kant's critical philosophy. After Kant's inversion of priority in the relation between time and movement, the tendency to chronologically order time is upset by contingently aberrant movements, movements of the ordinary, the advent of which are non-chronological. The inversion of priority demands new approaches to problems of time. Philosophy is pressured to create and connect and extend concepts *within* time, through processes of becoming, instead of assuming or appealing to previously existing forms *outside* of time. "The aim of philosophy," after the Copernican turn in temporality, writes Daniel W. Smith, "will no longer be to discover pre-existent truths outside of time, but to create non-pre-existing concepts within time" (Smith 2013, 381, Deleuze 2013). "Deleuze introduces time into the form of concepts. Concepts are not eternal and timeless (true in all times and all places), but are created, invented, produced in response to shifting problematics. In a sense, Deleuze is incorporating into philosophy the transformation that occurred in geology with the discovery of 'deep time'" (Smith 2020, 36). The creation of the concept of stratigraphic time in the dissertation aims for consistency with Deleuze's temporal vision of philosophy.

3.1 The Measure of Time in Science and Society

In pursuance of the perplexing problem of time in evolutionary theory, and its evasion of the problem despite evolutionary theory's roots in the discovery of deep time, the present chapter pivots to Poincaré, who joins the geologists awestruck by deep time (as well as by deep space), and acutely aware of the neglected problem of time in the sciences. In a preface to the English translation of *The Value of Science* (1907), Poincaré problematizes scientific presumptions to rules of constant and universal applicability, calling attention to the crucial role of *adventure* in science, of the value of venturing to where a rule's chance of success is least, for the sake of testing its constancy and universality. By problematizing a sedimented assumption underlying a rule, or by taking a rule to its limit in relation to an assumption, "by going very far away in space or very far

away in time, we may find our usual rules entirely overturned, and these grand overturnings aid us the better to understand the little changes which may happen nearer to us, in the little corner of the world where we are called to live and act. We shall better know this corner for having travelled in distant countries with which we have nothing to do" (Poincaré 1907, 7). The chronometrically enabled rules assuming temporal invariance constitute an assemblage of rules operative in scientific methodology and theory that Poincaré pursues with suspicion. Conceptual creations are enabled at the edge of such suspicion, concepts percolating in the problems explicated by the overturning of these normalized assumptions. The ethos of adventure and overturning strike some as irreverent, radical for the sake of provocation, or suffering from the allure of novelty, but it is simply an ethos acutely alive to scientific and philosophical exigencies no matter how deeply they problematize the assumptions of the past, no matter their power in guiding the disciplines. An overturning of an assumption does not always result in the elimination of the assumption. An assumption's force is rarely eliminated in one fell swoop, but rather chipped away, or as is often the case, it takes on a less eminent role within the conceptual network of a theory. The problematic structure of the EES is an exemplar of such an ethos (see
0.1-2 and 4.5).

The second chapter of *The Value of Science* concerns "The Measure of Time" (1898), an influential article in which Poincaré insists that the nature of time not only exceeds intuition, eluding psychological grasp, but also ineluctably exceeds the chronometric technologies, rules, and laws we invent in lieu of such an intuition. Not only does Poincaré bluntly suggest that scientists who "believe they possess this intuition are dupes of an illusion" (26), but also attacks chronometrically derived, or otherwise uncritical, assumptions of equality between two durations, between temporal intervals. Unable to determine the nature of time with appeal to intuition, scientists have recourse to chronometric procedures. The ostensibly basic mechanics of the pendulum posed formidable problems for scientists and philosophers of Poincaré's age concerned with determining the nature of time. The secretary of the Bureau of Longitude was highly suspicious of chronometric methods of warranting the thesis that "all the beats of [a] pendulum are of equal duration" (27). Since the day of Poincaré, no experimental research has evinced such equality of time, indeed quite the contrary (Callender 2011). It is well established that the appearance of such equality is in actuality only approximation, as "the temperature, the resistance of the air, the barometric pressure, [etc.] make the pace of the pendulum vary. … New causes, hitherto neglected, electric, magnetic or others, would [also] introduce minute perturbations" (Poincaré 1907, 27). Such variance is evinced by the necessity of continual chronometric correction, suggesting that temporality is irreducible to the presumably constant unit of chronometrically captured time. Temporal variation exceeds measurement. Chronometric conventions presupposing the invariant movement of time stubbornly pervade key functives, functions, and concepts of science and philosophy, as Poincaré points out (Poincaré 1907, 36):

> **We have not a direct intuition of simultaneity, nor of the equality of two durations. If we think we have this intuition, this is an illusion. We replace it by the aid of certain rules, which we apply almost always without taking count of them. But what is the nature of these rules? No general rule, no rigorous rule; a multitude of little rules applicable to each particular case. These rules are not imposed upon us and we might amuse ourselves in inventing others; but they could not be cast aside without greatly complicating the enunciation of the laws of physics, mechanics and astronomy. We therefore choose these rules, not because they are true, but because they are the most convenient, and we may recapitulate them as follows: 'The simultaneity of two events, or the order of their succession, the equality of two durations, are to be so defined that the enunciation of the natural laws may be as simple as possible. In other words, all these rules, all these definitions are only the fruit of an 'unconscious opportunism.'**

The methodological function of time's subordination to movement available to measurement is unconsciously ensconced in the practice of science, its observations, inferences, explanations, and theories due to the persistency of its pragmatic value, despite its reliance on unwarranted assumptions about the nature of time. Chronometrically contrived conventions—definitions, rules, principles, and measuring devices—unconsciously facilitate the operation of observational and experimental research programs by casting a temporally invariant plane of reference. The unconscious conventions have long functioned to subordinate time to chronometric movement with success, facilitating the production of rules and laws fundamental to the sciences.

Challenges to the uncritical assumption of chronometric temporality, challenges to the "unconscious opportunism" of pragmatically presuming the invariant passage of time have made minimal impacts on the sciences, for such a fundamental assumption cannot "be cast aside without greatly complicating the enunciation of the laws of physics, mechanics and astronomy" (Poincaré 1907, 36). The stakes are too high in the sciences, not to mention for daily life across societies, for time to become a true problem, and so a narrow perspective on the nature of time is perpetuated. Keystones of scientific methodology—testability, repeatability, and predictability— rely on a constant rate of temporal passage and the synchronized measurement of time. As the assumptions predominant throughout their respective histories attest, the philosophy of time and the evolutionary sciences are deeply biased by these chronometric conventions. Unconscious adherence to the subordination of time to movement lends itself to quite contingent and highly questionable presuppositions concerning the very nature of time, the modes of time available to chronometric observation, the temporal modes eluding measurement, and the implications for philosophy, science, and society. Poincaré is correctly careful not to draw from his skepticism about temporal concepts and chronometric constructs the conclusion that time does not exist or is an illusion but rather that we have not yet figured out how to conceptualize the nature of time beyond intuition and chronometric convention.

Poincaré's thesis concerning the conventionality of temporality refers to scientific experimental procedures, but these practices are not the only conventions constitutive of chronometric temporality. It also refers to philosophical assumptions concerning the nature of time and especially of simultaneity, astride philosophical conventions concerning physical and mathematical principles. Poincaré also refers to a matrix of French-based international conventions concerning the problem of the very measurement and chronometric distribution of the precise hour as a basic unit. The conventionality of temporality refers just as well to the technologies measuring and distributing times. Timepieces at the turn of the 20th Century were central to the lives of industrialized populations, novel technological features of a person's environment, drawing daily attention and sparking wonder in some about the nature of time, and its relation to the instrument of measurement. "Each of the three arcs of physics, philosophy, and technology," writes historian of science and physics Peter Galison, "carried with it a sense of the new. The 'new mechanics' advertised its rupture with old notions of mass, space, and time, the electric world-spinning telegraph cables was a celebrated triumph and tool of 'civilizing' empire" (Galison 2003, 315).

The chronometric revolution precipitated a new phase in the history of the problem of time, exemplified by the philosophical, physical, and practical breakthroughs of Henri Poincaré and Albert Einstein. Einstein adheres more insistently to physical exigencies than Poincaré, "more attendant to particular material machines rather than to the engineering of abstract ones" (Ibid. 316), and yet Einstein expressed, though sometimes uncritically assumed, a more strident perspective on the relations between theories and phenomena. Einstein's "On the Electrodynamics of Moving Bodies" (1905) insists on the importance of problematizing the synchronization of clocks. A chronometric technology and the practical problem of coordinating clocks across railway lines feature as problem agendas in one of the most influential papers in the history of physics. At approximately the same time period (1898), as a leading member of the French Bureau of Longitude, Poincaré begins his paper on the nature of time with a practical concern: the coordination of clocks to measure longitudinal differences, for the sake of determining distances between eastern and western points on the planet.

The practical problem of synchronization threw light on the problem of simultaneity, a particularly perplexing concept in physical theory (Galison 2003, During 2016). Poincaré's conceptualization of simultaneity emerges from his construction of temporal maps of coordination for the Bureau. Simultaneity does not implicate or entail an absolute time superintending temporal homogeneity across the globe. Simultaneity in the practical context occurs when clock *e*'s measurement of time is identical to clock *p*'s measurement of time, subsequent their calibration via cable signals between the clock sites. Clock coordination via telegraph had replaced astronomical observation as the standard of simultaneity. The telegraphic determination of longitudinal coordination becomes the basis from which connections spanning distant locations actualize in simultaneity. The breakthrough message of "The Measure of Time," from a practical point of view, is that the coordination of clocks necessarily requires the integration of transmission duration. The theory and experimental study of telegraphic signal transmission became a topic of great passion for Poincaré, so much so that he reviewed studies measuring the speeds of electrical transmissions, and started teaching courses concerning the theory in the 1890s—all percolations of Poincaré's proposal that simultaneity is ultimately a problem of *convention* (Galison 2003, 183). Poincaré demonstrated with carefully constructed time tables that a system of interconnected cables of communication around the globe could coordinate clocks. The chronometric subordination of time to measurement is the subordination of the problematic multiplicities of time to the technological movements of time-pieces in synchronization.

The problematization of time in science illuminates the technological condition of its practices and methodologies, and indirectly of its inferences, laws, rules, explanations, and theories, for chronometric technologies have effectively exteriorized temporality for the sake of assuming it invariant or for the purposes of experimental manipulation. Paleontologist Andre Leroi-Gourhan (1911-1986) develops a theory of "the exteriorization of time" in the third part of his magisterial

Gesture and Speech (1964), which becomes important in Chapter 6 in connection with the concept of rhythm in developmental and evolutionary biology. Time is exteriorized through technologies that maintain and bolster sociocultural norms of time keeping based on *idealizations* (Godfrey-Smith 2009, 2014) about temporal processes, presuming "ideally equivalent intervals." The "unconscious opportunism," the automatic penchant, to assume the nature of time reducible to these norms has biased the sciences, and "human time" more generally, to construe time invariant, merely linear, and metrically captured by technologies of measurement, when "measurement of lived time refers to phenomena unrelated to measurement as such" (Leroi-Gourhan 1993, 315-318). Time's subordination is clearly sedimented in the synchronized movements of mechanical clocks, tables, zones, and other chronometers of time
(Barbour 1999, Galison 2003). According to contemporary philosopher of time, Tim Maudlin, "…craftsmen and scientists continually try to improve the design of timepieces, to produce clocks that are ever more accurate and precise. But what is it for a clock to be 'accurate'? What we want is for the successive ticks of the clock to occur at *equal intervals of time*, or for the second hand of a watch to sweep out its circle *at a constant rate*" (Maudlin 2012, 15). The synchronization of engineered clocks demonstrates a deeply entrenched bias concerning the nature of time. Scientific technologies enabling carbon dating, DNA extraction and isolation, big data accumulation, and other techniques for situating relics into a unidirectional stream of time have collectively attracted and effectively catapulted the natural and human sciences, especially disciplines concerned with the evolutionary paths of hominin lineages. Paleontology, anthropology, the sweep of cognitive, brain, and behavioral sciences, and many other disciplines have become oriented around—and assume their progress established by—the time-stamps captured by these technologies, and the chronological story they weave.

Since "The Measure of Time" (1898), the problem of measurement has been a perennial component of the problem of time. More generally, the problems of measurement and of *measuring instruments* have since become components pressuring any scientific determination of truth. In this sense, the problem of measuring instruments, and of the activity of measuring more generally, is almost as old as science itself. The explanatory or conceptual role of measurement has become an exigent problem in all sciences. For instance, it is a thriving topic of debate in theoretical physics and philosophy of physics, specifically quantum physics (see Rovelli versus Wallace 2018). The measurement problem is more explicitly, intricately, and profoundly encountered in physics than in the earth, life, and social sciences. It is worth delving briefly into the variegated problem, which is growing in prominence, for the sake of emphasizing how deeply the *chronometric* subordination of time to movement runs in philosophical and scientific thought.

3.2 The Subordination of Time to Movement

Guided by Gilles Deleuze's philosophy of time (1994, 2004, 2013), the present chapter conceptualizes Poincaré's critique of science's "unconscious opportunism" by following Deleuze's problematization of time in philosophy, society, and science, focusing specifically on its tacit operation in evolutionary theory. Paramount to Deleuze's philosophy of time is time's long subordination to and relatively recent freedom from *movement*, including chronometric movement. The problem of time has perplexed philosophers for most of philosophy's history, and continues to perplex philosophers today. The various encounters with the problem of time one finds in the history of philosophy all illegitimately subjugate temporality to motion, as expressed in Deleuze in *Cinema 2: The Time-Image* (1985/2013)—an engagement with time focal to Deleuze's philosophy of time, and resonant with his other engagements with temporality (Deleuze 1966, 1994a; Deleuze and Guattari 1987, 1994b). The varied subjugation of time reckons time homogenous, invariantly passing with equal intervals, chronometrically captured, and linear in directionality, determining temporal singularities or anomalies as non-trivial events, as exceptions to the temporal rules of regularity. Deleuze offers a snapshot of the history of time's subordination in the following passage (Deleuze 2013, 39):

> **…if it is true that aberrations of movement were recognized at an early stage, they were in some sense corrected, normalized, 'elevated,' and brought into line with laws which saved movement, extensive movement of the world or intensive movement of the soul, and which maintained the subordination of time. … For a long time aberrations of movement were recognized but warded off. In fact, we will have to wait for Kant to carry out the great reversal: aberrant movement became the most everyday kind, everydayness itself, and it is no longer time that depends on movement, but the opposite…**

The inversion of time's subordination is fostered by the work of Isaac Newton (1642-1727) and Gottfried Leibniz (1646-1716), spurring what Deleuze calls "a Copernican turn in temporality" (Deleuze 2013, 271) in the work of Immanuel Kant (1724-1804), analogous to the paradigm shift from the earth-centric Ptolemaic model of the ostensible cosmos to the heliocentric model of our solar system (section 3). Akin to most revolutions, aberrant movements percolated for a long time prior to initial actualizations, which in turn took time to achieve more widespread acknowledgement, a slow and steady acknowledgement still very much underway, but gaining speed. The inversion not only requires a radical reconceptualization of time and movement, turning an intellectual axis of the West upside-down, but also the problematization of clock and calendrical temporal norms and institutions orienting, indeed ordering, daily lifeways. Time is now "out of joint…off the hinges assigned to it by behavior in the world, but also by movements of the world. It is no longer time that depends on movement; it is aberrant movement that depends on time … it is no longer time which derives from movement, from its norm and its corrected aberrations; it is movement as false movement, as aberrant movement which now depends on time" (Deleuze 2013, 271). Freed from movement, time's status is transformed into *an independent and autonomous multiplicity*.

Absolution of aberrance is a habit of thought readily apparent in the history of evolutionary theory (Dobzhansky 1974, Beatty 2010). The "unconscious opportunism" of time's subordination to motion, specifically chronometric movement, is a bias of convenience that paradoxically permeates evolutionary theory, as a theory concerned with change in earth's lifeforms over time, a theory born out of the geological discovery of deep time. The present chapter reconfigures the arrow-cycle dichotomy and its attempted reconciliations operative in the discovery of deep time, Darwinian theory, the Modern Synthesis (MS), and the Extended Evolutionary Synthesis (EES) in the light of time's various subordinations to movement in the history of philosophy. The explication of the problem of time in the history of philosophy and physics illuminates the problem of time in geology, evolutionary biology, paleontology, and so on, by *thinking through time's various subordinations to movement and measurement*, instances of what Poincare called an unconscious opportunism in the history of science.

Motion is not only a fundamental problem in physics but also in the earth and life sciences. Myriad problems of movement are perennially pursued in evolutionary biology at all levels of organization (or strata of assemblage in Part II): The movement of genetic information across generations, of populations across the earth, of organisms within populations, symbiotic movement between different organisms, the folding motions of proteins, and so on. The fundamental role of the concept of motion is expressed in the titles of two works by Darwin-- *The Power of Movement in Plants* (1880) aims to corroborate the theory of natural selection by marshaling observations and measurements of the phototropic, geomorphic, hydromorphic, and thigmotropic movements of plants in nastic response to the sun, gravity, water, and the physical contact (or *touch*) of other stimuli, respectively. Darwin infers general developmental principles about the functions of such sequential movements, inferences assembled to support the explanatory power of *decent by gradual modification* to account for behavioral change (or what is now called *phenotypic variation* and *phenotypic plasticity*). Darwin explains the repetitious patterns of movement as evolved products, evincing the capacity of plants to adapt to a variety of natural selective forces. The gradual rate of change inferred by Darwin presupposes temporal invariance, subordinating time to the observation and measurement of movement. Sections 3 and 4 of Chapter 1 explicate the chronometrically biased, merely linear, and always gradual temporal presuppositions of the MS. The EES forces a philosophically important exploration of time as a concept in relation to the temporal processes constitutive of evolutionary processes. The concept of stratigraphic time developed in Part 2 heeds Poincaré's critique, appealing not to intuition, nor inventing new directions or rules, yet still seeking to challenge the unconscious opportunism by taking the Copernican turn in temporality and conceptualizing the processes assembling the EES.

Time in the history of philosophy is variously subordinated to movement. The predominant conceptualization of time operative in antiquity is indexed on terrestrial movements, assuming temporality to be the generation and cessation of entities or events of earth. The planet's mutability, its susceptibility to change, contrasts sharply with the immutability of the eternal. Consisting of fluctuating terrestrial movements, time is subordinated to eternally recycling celestial movements. The multiplicity of terrestrial movement implies a multiplicity of temporality on earth, consequently precluding a standard of temporal measurement indigenous to the earth. Thinkers of antiquity turned to the atemporal celestial sphere in search of an immutable, immobile, and universally applicable measure of the earth's movements and their temporalities—they sought for a "most perfect movement," as it were. Conceptualization of the celestial measure allegedly standardizes observations, accounts, and evaluations of the temporalities of earth's movements. While conceptualizations of the relations between celestial eternality and terrestrial temporality vary, the subordination of time to movement is a thread of consistency running through Ancient, Medieval, and most of Modern thought.

Plato famously characterizes time in the complex cosmogony and cosmology of *Timaeus* as “the moving image of eternity” (Plato 360 BC, 37d). Eternity is a kind of ultra-movement, Über-movement, or movement of all movements, to which time is subordinated. The demiurge creates the universe according to an eternal model, as to a mutable, and ultimately perishable one (29a). Determining order preferable to disorder, the divine architect coordinates the previously unformed and perpetually mobile elements of earth, air, fire, and water, creating harmonious homogeneity, proportionality, intelligibility, and benevolence to the cosmos. Built into cosmic uniformity is a *circular movement*, founded as most fitting for intelligibility and rationality (34a). In truncated form, the demiurge assembles the elements of Sameness (x2), Difference (x2), and Being (x2) through mathematically proportionate procedures of fusion and fission, instilling the assemblage with an axis of circular motion, which subordinates Difference to Sameness by dividing the former into six parts while leaving the latter undivided. The assemblage forms seven unequal circles, the orbits of the celestial bodies, moving in opposite directions at two temporal rates (36c-d)—three of the circles move at the same speed while the other four move at singular speeds, and yet they move with proportionality. The complex yet proportional patterns of the celestial orbiting of the heavenly bodies is repetitious—hence Difference’s subordination to Sameness—returning to its beginning in completion of its “year,” its eternal circuit, or *eternal return*. The eternal repetition of celestial movement, the movement of all movements, instills an axis of standardization, a metric center, by which the plural temporality of terrestrial life may be measured.

The cosmogony and cosmology of *Timaeus* conceptualizes the *extensive* subordination of time to movement, but most of Plato’s dialogues are primarily concerned with the *intensive* movements of the soul. The dialogues are cherished by Neoplatonists as doorways to the ascent of the soul—the turning of the soul through and beyond sensibly perceived motions susceptible to change and disorder toward the invariant forms of intelligible and orderly being, toward the eternal essences of reality. For Neoplatonists like Plotinus (205-270), Porphyry (232-309), and Proclus (412-485), the ascent ultimately leads beyond the immutable forms of pure intelligibility to the One "beyond being"— or to God for the Medieval Neoplatonists like Augustine (354430), Dionysius the Aereopagite (5^{th} - 6^{th} Century), and Thomas Aquinas (1225-1274). The soul is tasked with ascending from lower levels of temporally variant movements of sensible being— with low degrees of intelligibility—toward the pure intellection of invariant and eternal forms, achieving increasing clarity of mind and harmony of soul along the way. The soul and its proximity to the invariable and impermanent light of the eternal movement of the cosmos depends for its existence on the atemporality of the latter. Temporal sensations and intellections are diminished states of the soul, subordinated to the pure intellection of forms and ultimately to the One or God. The intensive ascent of the soul moves upon a hierarchically structured path of procession and reversion. The time of the soul is subordinate to its movements upon this path.

The subordination of time to movement becomes more straightforwardly articulated in the philosophy of Aristotle, whose notion of time captures the heart of the subordination in elegance, conceptualizing time as "the number of movement" (Aristotle 2008, *Physics*: 219b5-8). Aristotle's natural philosophy is guided by the principles of *change* and *motion*, packed into which are problems and concepts inherited from Pre-Socratic and Platonic philosophical doctrines. When Aristotle conceptualizes the nature of time, temporality becomes thinkable through the principles of change and motion, which are necessary for time, for cognition of the passage of time without the mutable movements of entities and events—without cognizing extensive and intensive movements changing in the natural world and the soul. The tripartite parsing of change into kinds of magnitude—extension, continuity, and transition—enable experience and measurement of change as passages between befores and afters. Changes in magnitude constitute a continuum of change. Chronometers are capable of capturing continuous intervals in number but not the intervals themselves, for time is not itself movement and change, but rather the counting and calculating of continuous intervals of movement and change. The intervals of the movement of celestial bodies provide for Aristotle, as they did for Plato, a counting apt to standardize temporal measurement of other bodies. Counting intervals of befores and afters assemble sequences. Sequences numerically measured according are ordinal successions of instants. Now moments are either instants of difference or presents of sameness.

Numbered movements assemble a sequence ordered according to chronologically, and perhaps causally, linked instances identified as “before” and “after” in relation to a targeted instant within the sequence: “time is the number of motion in respect of before and after” (Ibid. 219b2). Time is the numerical measurement of the befores and afters of movements. When one thinks of *number*, one might well think of counting, in the form of a sequence (e.g. 1,2,3), which orders entities of the earth, or which count up or down in reference to an event’s advent, its cessation, or duration. The befores and afters that an observer or a device measure mark the commencements, durations, and completions of changes, of modifications in the movements of entities or events. Motions are the targets of measured changes, the marks of perceived salience within the flow of entities and events indicating difference, inciting a measurement of movement *x* in relation to movement *y*. When one ascribes a number to an entity or an event, when one marks the advent or cessation of a thing or happening, and when one numerically records the duration of an event one is counting the movements of an entity or the movements of the assemblage of variables constitutive of an event. The quantitative measurement of salient differences between instants assembles a timeline of sameness marked by significant moments of differentiation.

Metric technologies and other time-keeping procedures reckon moments as instants of difference, instants that are qualitatively related to the present moment, which serves as an invariant substratum of sameness for the flow of differences, for the moments before and after the present moment. Present moments mark movements of entities and events, both connecting and divide time with sameness enabling a differentiated sequence. As instants, now moments are measured by ordinal numbers. Numbered moments (i.e. instants) marking intervals are either their beginnings or endings. The present moment is indivisible and invariant, and yet differences are necessary for the continuous passage of time. The Aristotelian approach presupposes that the sameness and continuity connecting the movements of entities and events are conditions for the difference and discontinuity constitutive of or breaking up an observed sequence or assemblage of distinct sequences. An invariant movement of the physical earth grounds temporal difference and discontinuity in temporal sameness and continuity, which is codified in the practice of numerical measurement. A critic of the Aristotelian concept of time may censure this presupposition: variable time is subordinated to invariant movement *masked* as time itself. An invariant temporal movement beyond the differentiated flow of temporalities characteristic of distinctive entities and events is given primacy. The Aristotelian presupposition is part and parcel of the "unconscious opportunism" of scientific theory and practice identified by Poincaré, part and parcel as well of the bias's operation in the history of philosophy, in relation to the problem of time.

3.3 The Copernican Turn in Temporality

Subterranean aberrations of movement lurk in the subordinations of antiquity in its various extensive and intensive modes. Percolations of time's liberation from movement prepared in the ineluctably anomalous and unpredictable perspectives of sublunary life where, as philosopher of time, science, and technology Michel Serres quips: "scientists can predict the time of an eclipse, but they cannot predict whether they will be able to see it" (Serres 2000, 67; Smith 2013, 379). Lunar observations can be chronometrically captured and predictions of lunar movements successfully cast, but the relations between sublunary observers and lunar patterns of movement are always ineluctably variable and susceptible to change. Discrepancy between the lunar and sublunary realms begs the question of whether the latter is controlled by the former. Is the aberrant and unpredictable earth subordinate to the laws of lunar movement or is its anomalous multiplicity of movement independent and autonomous from its ordered movement? The discrepancy and its problematization precipitates conceptual and practical crises, concomitantly prompting an unavoidable decision: salvage the priority of movement or accept—even will—the independence and autonomy of time.

Dan Smith (2013) acutely contrasts rural and monastic temporality with ordinary temporality. The extensive rhythms of *rural time* flow according to agricultural reference points indexed on the originary temporal patterns of the earth, which mix with the intensive rhythms of *monastic time* flowing according to its references to originary temporal patterns of worship, spirituality, and interiority. Contrastively, the *ordinary time* of city life flows according to Reformationist and capitalist norms and institutions. Rural and monastic temporality attempts to maintain the primacy of movement and time's subordination to its extensive and intensive modes while city temporality embraces the liberation of time with all of its contingency and unpredictability. The latter is not derived from a prime movement, nor is it indexed upon originary time, but is rather ordinary time. The intensive monastic profession of the soul to faith in God in conjunction with the extensive profession of one's economic activity (as articulated by Max Weber) are eventually captured by the capitalist norms and institutions of temporal activity (as articulated by Karl Marx). "The abstract time of capitalism," writes Dan Smith, "became the concrete time of the city" (Smith 2013, 381). The temporality of urban everydayness is freed from deference to the eternal, freed to actively encounter the advent of the new, the novel productions of the earth in all of their contingency and multiplicity.

Meanwhile, in the theoretical alcoves of the city, an epistolary quarrel between Newton's concept of absolute time and Leibniz's concept of relational time prepares for Kant's liberation of time from movement. The famous philosophical, theological, and scientific debate of 1715-16 between Leibniz and Samuel Clarke, a representative of Newton, exhibits the contrast between Newton's absolute conceptualization of time (and space) and Leibniz's relational conceptualization of time (and space). The concept of relational time maintains the priority of movement, offering a novel approach to time's subordination. Newton's especially innovative concept of time proposes a break from such subordination, prioritizing time and therein initiating the liberation of time from movement, which comes to fruition in Kant's philosophy of time. Leibniz's *relationist* concept of time is often captured in simplifications prone to harbor and spread misconceptions concerning the complex concept. Predominant in the simplifications are reductionist characterizations of Leibniz's relationist concept. J.A. Cover (1997) perceptively and carefully discerns a variety of reductive strategies adopted by explicators of Leibniz's concept. Readers compelled to delve into the details of these strategies, generally compelled to untangle the nuanced complexity of Leibniz's philosophy of time, are encouraged to acquire Cover's work. The following explication is admittedly a simplification, yet one informed by Cover's more careful exposition. The simplification is motivated by an attempt to explicate the "received" reading of Leibniz's concept, to highlight a genre of positions identified in the wake of the concept's reception called *relationist*, rather than to dig deeper into the structure and content of Leibniz's philosophy of time. The latter task is of course of utmost importance, yet the received view is tantamount to capturing Leibniz's contribution to the history of time's subordination to movement as an instance of science and philosophy's unconscious opportunism regarding the problem of time.

As articulated by Cover, "there is little disagreement about reckoning Leibniz a sort of *reductionist* about space and time" (Cover 1997, 289). Cover delineates three central aspects of the generally received view of Leibniz's reductive relationism:

(1) Contrary to Newton's concept of absolute time, relational temporality is nothing apart from the bodies and relations between these bodies, which are contained in time, such that the nature and indeed the very existence of time are determined by contained bodies and the relational ordering obtaining between them. Leibniz bluntly censures absolute time and space in the correspondence with Clarke: "Space 'out of the world' or 'empty space within the world' is 'imaginary'" (Fifth Paper, Section 33); "Instants, considered without the things, are nothing at all" (Third Paper, Section 6); "The reality of space in itself [or of time in itself]" is only a "chimerical supposition" (Section 5); "Space in itself is an ideal thing, like time" (Third Paper, Section 33).

(2) Akin to bodies, temporal relations are reduced to "well-founded phenomena"—ostensive ways of the world, which are ultimately false, yet nevertheless appear persistently to human perception. Such phenomena are distinguished from hallucinations and dreams in that well-founded phenomena are grounded in the ways of the world. Time's existence is therefore grounded in the world, but only in a secondary, derivative fashion. Time is derived from individual substances, their properties, and the relational movements obtaining among them.

(3) Explanatory accounts of causal succession obtaining among relations of individual substances should eliminate appeals to time as a ground upon which the causal

> relations assembling the succession can be explained. Relational sequences of causal succession are not dependent upon time. Temporal instants are rather reduced to causal relations between the movements of intrinsically active substances. Causal concepts are thereby more fundamental to Leibniz's philosophy than are temporal concepts.

The three central aspects of Leibniz's philosophy of time clearly evince the subordination of time to movement. These aspects are explicated through the concepts of succession, coexistence, and permanence, which are addressed below. While Newton's concept of time is necessary for Kant's liberation of time, the reconfiguration of Leibniz's three concepts by way of the process of synthesis is crucial to time becoming autonomous and independent from movement.

In Newton's Scholium on space and time in *Mathematical Principles of Natural Philosophy* (1687), the philosophical mathematician and physicist initiates time's liberation from movement with the conceptual creation of "absolute, true, and mathematical time (that) of itself, and from its own nature, flows equably without relation to anything external, and by another name is called duration: relative, apparent and common time, is some sensible and external (whether accurate or unequable) measure of duration by means of motion, which is commonly used instead of true time" (Newton 1687, Scholium Paragraph V). The existence of absolute time is independent from and inaccessible through human perception. Human perception is only capable of reckoning relative temporality via measurement. Temporal inferences are drawn from the movements of observationally available entities. Absolute time is only mathematically captured. In clear contrast with relational time, Newton's concept of absolute time is irreducible. Relational time is rendered relative time, a measurement inferred from individual substances and their relations. Newtonian time is often metaphorically represented as a container in which or stage upon which physical phenomena are in motion in a completely deterministic manner. If the container were empty, if no actors animated the stage, absolute time would persist unaffected by the absence of physical entities and motions.

Newton conceptualizes time as a universal clock. Global instants of time are equably spread out over space with regularity, they are linearly ordered universal *moments*. Time is the same for everyone everywhere: "The moment of duration is the same at Rome and at London, on Earth and on the stars, and throughout all the heavens" (Ibid.). Sets of simultaneously occurring events are connected by universal moments. Time passes progressively in a succession of moments with regularity. The equally spaced moments of this succession are facilitated in human norms and institutions, in mathematics and sciences, by chronometric methods and technologies capable of regularly counting moments as seconds, minutes, months, years, etc. Even though such equality is contrived, and incapable of proving universal synchrony across the terrestrial and celestial spheres, instead of forming a hypothesis of complexity apt to accommodate temporal inequalities in the universe the scientific method guides Newton to establish a simple hypothesis, until counteracting observations force a more complex one, as articulated by Wolfgang Rinder (2001, 63): "That simpler hypothesis is the temporal homogeneity of physics: any two physical experiments which are local, that is, isolated from the rest of the universe, and which are of equal duration now, can be repeated at all future times with equal outcome. And since all clocks are in principle based on repetitive 'experiments,' this ensures the permanent synchrony of all imaginable clocks." The concept of absolute time and the universal clock hypothesis mathematically modeled by Newton are necessary for the functional meaning he ascribes to the basic laws of mechanics.

Newton's concept of absolute time gives temporality independence from motion, breaking away from over a millennia of subordination, opening up the problem of time to novel approaches. Kant carries out time's liberation, ascribing both independence and autonomy to temporality. Newton's concept of time still harbors subordination, however, for the formulation of the laws of nature function as enabling conditions of our explanations of everyday temporality, excluding the importance of aberrant temporalities. The only way time controlled by the laws of motion explain the human capacity to keep appointments, as analyzed by Julian Barbour (1999), is by explaining how watchmakers construct synchronizable measuring devices. These devices are not synchronized with time itself, but rather attuned to themselves. The Newtonian explanation of synchronized behavior looks behind or underneath observed patterns of behavioral phenomena to posit in a way analogous—though ultimately very different from Kant's rational methodology—their conditions of possibility, conditions which happen to be clock mechanics and technological codification. The impact of Newton's natural philosophy on science's relation to time and space is deep. The unconscious opportunism of science to continue subordinating time to space is made possible by the Newtonian explanation of mechanics and especially of the acceleration of time-keeping technologies, which carve the unconscious opportunism even deeper into the fabric of scientific activity and theory.

Philosopher Elie During suggests that one of the greatest achievements of Immanuel Kant (1724-1804) "consisted in claiming with utmost vigor that 'time' properly understood is not an object in any meaningful sense, but something like a formal intuition, or a second-order concept" (During 2016, 1-2). Kant's transcendental epistemology conceptualizes the form of time in a way heavily influenced by the scientific niche of the 18th Century, especially by Newton, drawing attention to the danger of unconsciously projecting content into the framing of the form. The filling of the form with historically contingent aspects of content is in evidence in Kant's reckoning of the relation between temporality and causality in the *Critique of Pure Reason* (1781), where the form of time is used according to pure intuition to affirm the fundamental mode of succession when determining the causal relation between event A and event B despite instances in which A and B appear in experience as simultaneous (coexistence, along with permanence, is another fundamental mode of time). The causal commitments of Newtonian science compel Kant to elevate the mode of succession, with implications for Kant's conceptualization of causality. Darwin's gradualist solution to the problem of deep time assumes this bundle of commitments as well.

The Critique of Pure Reason (1789) develops a transcendentally structured exposition of time (and space), establishing very early in the work the doctrine's prominent role in Kant's critical project—a constructive project determining in thought the universal conditions necessary to enable succession, outer sense, and a valid representation of the external world. Kant's metaphysical and transcendental exposition of time (and space) deduces temporality (and spatiality) as pure forms of intuition. The forms of space and time are themselves singular objects of *a priori* knowledge, purported to serve as the epistemic basis of classical mathematics and physics. Space and time are not bundles of sense data but pure intuitions, pure forms in which the particular objects are presented via the senses. All thought for Kant is ultimately related to intuitions, and generally to sensibility. Kant defines sensibility as "the capacity (or receptivity) to acquire representations through the way in which we are affected by objects" (A19/B33). Sensibility is the lone generator of intuitions, which we think through the understanding, giving way to the advent of concepts. (A20/B34).

Contrary to relational time, Kantian temporality is not relative to things: "We cannot represent to ourselves the absence of space, though we can quite well think it as empty of objects. It must therefore be regarded as the condition of the possibility of appearances, and not as a determination depended upon them" (A24/B38-9). All things that move and change do so in time, while time is itself immutable and utterly static. Time is not an eternal form, but rather the form conditioning everything that is not eternal. Neither is time a feature of things as they exist independently of our knowledge of them. If space and time were positioned in things in themselves (noumena), they would be unknowable, but Kant thinks time and space are objects of synthetic a priori knowledge. The form of time is no longer filled by intensive and extensive movements, nor is it filled by succession, coexistence, and permanence. Kant rethinks Leibnizian succession, coexistence, and permanence as modes or relations of time itself, but time and space are themselves irreducible to their relations (or modes), irreducible to their contents, and their immutability as pure forms is irreducible to their permanence, for they are rather the conditions for perception of spatial and temporal modes, contents, and permanence. Kant reconfigures Leibniz's concept of space as a "purely relative…order of coexistences" and time as an "order of successions" (Leibniz and Clarke 2000, 14)[2], establishing the self as deeply and thoroughly temporal, persisting in time via states of coexistence and succession. Time itself as pure and empty form actually occurs through the activity of *synthesis*, whereby the self productively actualizes not time itself but the modes or relations of time, reckoning being and knowing possible. Kant thus revises the three dimensions along which time was previously construed by Leibniz, transforming the modes (or relations) of time through synthesis (Kant 1998, A 176/B 218). *Succession* is the rule of *difference* of sequential contents occurring at various times, the synthesis of time's parts, *coexistence* is the rule of *sameness* of content from time to time, the synthesis of temporal contents, and *permanence* is the rule of content threading *all times* via synthetic passage through successive and simultaneous states. *Succession* involves a multiplicity of different parts requiring the self to synthesize this multiplicity of appearances by fixing them in the present, coping all-the-while with the oncoming variability of the present. *Coexistence* or simultaneity produces knowledge by not only apprehending different parts in the present, but also by reproducing parts from the past through the

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[2] "I hold space to be something merely relative, as time is … I hold it to be an order of coexistences, as time is an order of successions. For space denotes, in terms of possibility, an order of things which exist at the same time, considered as existing together; without enquiring into their manner of existing. And when many things are seen together, one perceives that order of things among themselves" (Leibniz and Clarke 2000, Section 4).

activity of memory, by synthesizing past parts with present parts. The *permanence* of a variable that endures through the production of present parts contracting reproduced parts of the past synthetically *recognizes* a concept of known experience (e.g. "this must be a tree").

When time becomes freed from psychology and cosmology, time's status is transformed. The Copernican revolution of temporality gives time autonomy and independence from the movements of the divine, of the world, or the self, which become illusions of transcendence.

Time becomes dependent only on itself while movement becomes dependent only on time. Movement now takes place *in* time. Time and space are pure and immutable forms independent and autonomous from changes and movements in time and space. Time is no longer "numbered movement," no longer chronometrically captured movement. Time is freed from its support role as the measurement of movement. No longer is time the moving image of eternity, nor the counting of movements, nor numbered measurement of counted movements according to standardized units of regularity. Time takes a novel form of ordinary everydayness, whereby movements outside of the norm are not judged according to an eternal heaven of immutable forms, nor coerced into standard modes of measurement, but rather related to the productive advent of the new. The liberation and consequent problematization of time's nature perplexed 19th and 20th Century art, science, and philosophy, becoming a frequent theme, or otherwise subterranean influence. The new status of time tacitly and explicitly opens the doors to novel theories of and experimentation with the dynamics of time—whether through art, science, or philosophy, perhaps through their constructive juxtaposition. Forays into the unhinged nature of time are ventured in the poetry and philosophy of Friedrich Hölderlin (1770-1841), Sören Kierkegaard (1813-1855), and Friedrich Nietzsche (1844-1900), the economic work of Karl Marx (1818-1883) and Friedrich Engels (1820-1893), the psychological theories of Sigmund Freud (1856-1939) and Carl Jung (1875-1961), in the Modernist literature of James Joyce (18821941) and Marcel Proust (1871-1922), and of course in the physical theories of Henri Poincaré and Ludwig Boltzmann (1844-1906) to name just a couple. An instructive exchange between philosopher Henri Bergson (1859-1941) and physicist Albert Einstein (1879-1955)—an exchange redolent of the epistolary quarrel between Leibniz and Newton, though the structure and content of the former is quite strikingly distinctive. The exchange has been controversially and confusedly received over time, but has recently become revived for the sake of mining new insight alive to contemporary physics and philosophy through more careful analysis and evaluation unique in the history of its reception (Canales 2016, During 2007, Scott 2006). The transdisciplinary revolution in temporality also prepared for a plurality of novel philosophical approaches to the problem of time, notably in the work of Edmund Husserl (1913, 1928), Alfred North Whitehead (1920, 1928), Martin Heidegger (1927, 1962), Jean-Paul Sartre (1943), Gilbert Simondon (1989), Michel Foucault (1966), Jacques Derrida (1967), Paul Ricouer (1983-89), Michel Serres (1995) and of course Deleuze. The contest of conceptualizations has catalyzed a plurality of novel encounters with the problem of time.

3.4 Time as Pure and Empty Form of Change

> *As far as philosophy is concerned…time is not itself a process, but the form of any process. It is a formal concept. What this means is that 'time' is essentially the name of a problem, or a cluster of problems, rather than a general denomination subsuming a class of particular objects (whether we call these 'durations' or 'changes').*
>
> \- Elie During (2016, 7)

The problem of time is notoriously challenging, as time is not something to be discovered as an object somewhere in the universe: "…time does not lend itself to scientific or philosophical inquiry as an objective natural property, or a bundle of such properties universally attached to phenomena given in time" (During 2016, 1). Therefore we should not expect to find empirical confirmation of time (Salanskis 2019). The commonplace claims that time does not exist are consequently rendered suspect (see Barbour 1999 and Folger 2007 for such claims, and Rovelli 2018 for the weaker claim that time is an emergent phenomenon), for they presuppose that the best way (perhaps the exclusive way) to determine whether time exists is to treat time as any other scientific object should be treated, expecting hypothesized properties or behaviors of time to be given confirmation through metric technologies and experimental programs. The absence of evidence for time's existence, according to such claims, is indeed evidence of time's absence. The dissertation regards debate around the very existence (or non-existence) of time a false problem. The allure of the false problem is the strong tendency in physics and philosophy of physics, indeed in everyday ways of time-keeping, to think time ontologically. "The physical world as described by our best physical theories does not require time … meaning our best physical theories can do without, or can find a way around it" (During 2019, 56:00). Influential physicist Carlo Rovelli's work on quantum gravity is an intriguing example attracting an impressive amount of attention (Rovelli 2004).

Poincaré is correctly careful not to draw from his skepticism about temporal concepts and chronometric constructs the conclusion that time does not exist or is an illusion but rather that we have not yet figured out how to conceptualize the nature of time beyond intuition and chronometric convention. If continuous variation is irreducible to ontology, the problem of time itself forces philosophical conceptualization irreducible to everyday experience and physical science. The deepest divergence between philosophy and physics is that concept creation does not stop with the ontologically determined and empirically captured modes and tempos of continuous variation—of the sufficient reason for the advent of the new—but is forced to think the transcendental conditions of the real experience of actualized time, entailing the problem of time itself (as continuous variation). The poorly posed problem of time's ontological status effectively blinds philosophers and physicists to the difference in kind between time itself— conceptualized as continuous variation—and the modes and tempos of time, the actualized variations of which legitimately raise ontological problems.

The problem of time has generated at times quite fierce interaction between philosophers and physicists which, in the past 100 years has resulted in an ethos of continuity between philosophy and physics, and consequently a loss of philosophical autonomy. “Philosophy of physics, “ writes influential philosopher of time, Tim Maudlin, “is continuous with physics proper. The sorts of questions we will ask are among the questions physicists ask, and among the questions physical theories traditionally tried to answer. But an astonishing amount of physics can proceed without answers to these questions” (Maudlin 2012, xi). Philosopher Elie During thinks otherwise: “…philosophers and physicists do not agree on what kind of questions should be asked in the first place. ... the main issue is that they do not agree on the issues” (During 2019, 31:00, 42:00). During aims to “raise the proper questions” by developing “an agenda for a proper philosophical processing of the issues of time… [which] takes the form of *an apology for time as form*, as opposed to an object” (During 2019, 52:00). The premise of *time as object* is a false start, for such a premise precludes *a priori* conceptualization of time. The problem of time is unlike all other problems, including the problem of space, for the concept of time does not relate to things, it is not a thing-concept, as it were, and so demands of thought a genuinely unique conceptual approach. During thinks of “time” as “essentially the name of a problem, or a cluster of problems, rather than a general denomination subsuming a class of particular objects (whether we call these ‘durations’ or ‘changes’)” (During 2016, 3). Time as form is used by the philosopher as a key tool for framing the problem of time irreducible to ontology. Time is irreducible to process, which involves modes and tempos of time, not the form of time. The only way to make sense of time is to conceptualize how temporal processes operate, not on time itself, but on time’s modes and tempos.

Elie During aptly suggests that one of the greatest achievements of Kant "consisted in claiming with utmost vigor that 'time' properly understood is not an object in any meaningful sense, but something like a formal intuition, or a second-order concept" (During 2016, 1-2). Kant's transcendental epistemology conceptualizes the form of time in a way heavily influenced by the scientific niche of the 18th Century, especially by Newton, drawing attention to the danger of unconsciously projecting content into the framing of the form. The filling of the form with historically contingent aspects of content is in evidence in Kant's reckoning of the relation between temporality and causality in the *Critique of Pure Reason* (1781), where the form of time is used according to pure intuition to affirm the fundamental mode of succession when determining the causal relation between event A and event B despite instances in which A and B appear in experience as simultaneous (coexistence, along with permanence, is another fundamental mode of time). The causal commitments of Newtonian science compel Kant to elevate the mode of succession (see Chapter 3). Darwin's gradualist solution to the problem of deep time assumes this bundle of commitments as well (see Chapter 1 and Chapter 4).

Time assumes a new status of *independence* and *autonomy*, depending only on itself, as the *pure and empty form of change,* as *continuous variation* (Kant 1998, Deleuze 2004). The aberrant movements of the earth depend on the pure and empty form of change for a multiplicity of directions, not on cyclic and linear movements measured by chronometers. Temporal measurements are derivative modes of time. Time as the pure and empty form of change, as continuous variation, is the transcendental condition of the three forms of repetition, which Deleuze explicates in terms of three passive and active syntheses of time (Deleuze 1994, 2013). Time as such is the transcendental condition of the three forms of repetition, which Deleuze explicates in terms of three passive syntheses of time.

During makes a compelling argument through the work of Bergson, Whitehead, and others, about the persistent reduction of time to succession eclipsing other temporal modes, specifically coexistence. The true problem of time as multiplicity is the problem of coexistence (or simultaneity): "In the conceptual framework set up by Bergson, duration's main contribution to time consists in shifting our attention to the third aspect or profile of time identified by Kant, namely: coexistence. Simultaneity, then, rather than the succession of present and past, but a simultaneity that takes its full meaning once we acknowledge their difference in nature" (During 2016, 16). Beyond the crucial critical claim that temporality is irreducible to chronometric homogeneity, "it is equally important to understand how heterogeneous durations unfolding together across the universe come to be woven into the fabric of the evolving universe" (During 2016, 2). Heterogeneous temporality as the medium of coexistence must be unearthed from beneath perceptions of temporal motions and metric durations, must be conceptualized on the plane of thought. Two spatially separated events are simultaneous when they happen together in time. Simultaneity is irreducible to non-succession, as Kant argues against Leibniz. Suspicion of "global" concepts of time, of time in general, or time itself is a healthy suspicion, in consideration of the great variety of local durations of actual, observable, and measureable changes, but such suspicion becomes too stringent when concepts of time are rejected outright. While it may be a wild goose chase to search for a "single concrete duration embracing all local durations" (Ibid. 6), like a container of all instants past and future awaiting our discovery somewhere in the world or universe, the attempt to conceptualize time irreducible to the multiplicity of local times is not useless. During's conceptualization of the coexistence of an always changing stratification of temporalities resonates with Deleuze's description of "'the most fundamental operation of time' [Deleuze 2013], which is the unceasing production of a present contemporaneous with its own past as virtual" (During 2016, 16).

The problems of coexistence and novelty demand concepts of non-chronological temporality. Deleuze's *Cinema 2: The Time-Image* makes speedy yet impactful claims about the non-chronological nature of time. After Kant's inversion of priority in the relation between time and movement, the tendency to chronologically order time is upset by contingently aberrant movements, movements of the ordinary, the advent of which are non-chronological. Deleuze conceptualizes these non-chronological modes of time in a highly unique fashion, but such is called for in response to such a challenging problem. Even if Deleuze's conceptualization is too idiosyncratic and empirically intractable, it is a task infrequently encountered in the philosophy of time, and so Deleuze's concepts open a provisional (and compelling, at least according to the present effort) juncture needed for a philosopher or scientist to begin. Non-chronological time is "the perpetual foundation of time" (Deleuze 1985/2013, 81). The virtual manifold actualizes the temporal syntheses through non-metric and non-chronological processes. For individuals in the Kantian framework time is the very form of interiority, of inner sense, whereas for Deleuze individuals are interior to time, and "…the only subjectivity is time, non-chronological time grasped in its foundation, and it is we who are internal to time, not the other way round" (Ibid, 85). Thought or the brain, according to Deleuze, is "the set of non-localizable relations" between what he calls "sheets" of affecting and being affected, of active and passive syntheses (Ibid, 125). These relations are non-localizable in that they transverse domains or strata of synthesized temporality via non-chronological processes of differenciation between virtuality and actuality. The multiplicity of non-chronological temporal processes neither emerge from nor eventualize between actual movements or events, but are rather individuations of a virtual field of coexistence, of infinitely variable singularities. Time is non-chronological in that the past is not composed of linear sequences between befores and afters. Chronometric measurements of time depend on a temporal manifold of pre-individual and non-linear singularities. The nonchronological nature of purely virtual time consists in the coexistence of the past with the present it was previously, and "the past is preserved in itself, as past in general (non-chronological); at each moment time splits itself into present and past, present that passes and past which is preserved" (Ibid, 85). The pure past and the passing present split in homogeneous directions, and are thus resistant to chronological sequencing. The paradoxical characteristics of nonchronological time are "the pre-existence of a past in general; the coexistence of all the sheets of the past; and the existence of a most contracted degree" (Ibid, 99). Non-chronological time is "extracted" from the strata of the past in the present by constituting "a sheet of transformation which invents a kind of transverse continuity or communication between several sheets, and weaves a network of non-localizable relations between them" (Ibid, 123).

3.5 The Problem of Time and the Form of the True

> *If we take the history of thought, we see that time has always put the notion of truth into crisis. Not that truth varies depending on the epoch. It is not the simple empirical content, it is the form or rather the pure force of time which puts truth into crisis.*
>
> Gilles Deleuze, *Cinema 2: The Time Image* (2013, 130)

The present philosophical conceptualization of the unconscious opportunism as the subordination of time to chronometric movement and consequent assumptions of temporal invariance culminates in the problematization of truth. Catalyzed by Kant's concept of time, Deleuze problematizes the variable concept of truth, the traditional target of philosophy and science, the high stake involved when Poincaré accuses philosophy and especially science of an unconscious opportunism pertaining to the problem of time. Philosophy is pressured to create and connect and extend concepts *within* time, through processes of becoming, instead of assuming or appealing to previously existing forms *outside* of time. "The aim of philosophy," after the Copernican turn in temporality, writes Daniel W. Smith, "will no longer be to discover pre-existent truths outside of time, but to create non-pre-existing concepts within time" (Smith 2013, 381, Deleuze 2013). "Deleuze introduces time into the form of concepts. Concepts are not eternal and timeless (true in all times and all places), but are created, invented, produced in response to shifting problematics. In a sense, Deleuze is incorporating into philosophy the transformation that occurred in geology with the discovery of 'deep time'" (Smith 2020, 36). "That we are in time looks like a commonplace," writes Deleuze in *Cinema 2: The Time Image* (1985), and "yet it is the highest paradox. Time is the interior in us, but just the opposite, the interiority in which we are, in which we move, live, and change" (Deleuze 2013, 82). "The philosopher," writes Deleuze, "readily presupposes that the mind as mind, the thinker as thinker, wants the truth, loves or desires the truth, naturally seeks the truth. He assumes in advance the goodwill of thinking; all his investigation is based on a 'premeditated decision'" (Deleuze 2013, 94). The "premeditated" philosophical search for truth is assumed to be an attempt to achieve agreement between minds regarding the organization of concepts, "so many explicit significations or formulated truths," separated from unreliable and ever-changing sensuality (Ibid). Truth's element of *intensity* is perpetually obscured, as truth has been secured in systems of propositions, in terms of the *correspondence* of knowledge, the mind, or subject and the matter "at hand," the thing, or object; the propositional statement, the linguistic medium of truth, is judged as *correct* (as opposed to in *error*) only when it directs itself accordingly to the target. The problems of temporality and causality, and their resonances and interferences, are crucial in evolutionary science and philosophy, as exemplified by natural selection's necessary implication or logical entailment of the gradual pace of evolutionary change. While the intermediary processes of selection's gradual operation on variation is insensible, it is not unthinkable. Philosophy of nature affirms the transcendental principle of *intensity* as a necessary condition for conceptualizing the insensibility of evolutionary history. The role of intensity in relation to stratigraphic time, its role within philosophy of nature, and what it can do to assist in the conceptualization of the EES are reprised in the final chapter.

The Copernican turn in temporality problematizes the status of the true and of the false. Temporal problematization of the form of the true and affirmation of *the powers of the false* challenge evolutionary theory's claims to traditional truth and traditional time. The concept of truth is contested in many ways in the history of philosophy, some of which contest the content of truth—the truth-claims of the past—by challenging their fulfillment of the conditions for truth-claims (necessity and universality). Deleuze's challenge is deeper, problematizing not truth's content but its very form. In the history of thought concerning truth, it is only the true that has a form, while the false has no form. The lineaments of the traditional form of the true are universality, necessity, and eternality. When real states of affairs are represented by true propositions, universal, necessary, and eternal essences are purportedly captured. When images, appearances, and passions cloud mind and body, essences become confused in the translucency of cognition's relations to the real, leading to error—the unformed effectuation of the false. Falsity confuses the real and the imaginary, essence and appearance. When the form of time challenges the form of the true, powers of the false are freed from its subordination to the form of the true. The false is neither formed nor unformed, but rather conceptualized anew as a manifold of powers. The powers of the false are powers of transformation, of creation. The power of the false creates a new concept of the true, a concept imbued with the form of time. The true becomes conceptualized as manifold singularities created *in time*, rather than as a universal, necessary, and eternal form outside of time. The powers of the false are temporal multiplicities, passive and active syntheses, modes of repetition productive of novelty. "…contrary to the form of the true which is unifying and tends to the identification of a character (his discovery or simply his coherence), the power of the false cannot be separated from an irreducible multiplicity" (Deleuze 2013, 133). The irreducible multiplicity of temporality pressures evolutionary theories to newly conceptualize not only evolution's modes but also its tempos (ala Simpson 1944, Deleuze 1968, and Gould 1985).

The turn in temporality demands new approaches to temporal problems for it upsets the relation between time and movement, the tendency to chronologically order time, through affirmation of contingently aberrant movements, movements of the ordinary, the advent of which are *non-chronological* in character. The chronometric subordination of time precludes the problematization of temporality due to the observation of its continuous variation, and consequently non-chronological virtuality, but rather captures observed aberrations of movement within its chronometric net, relegating them to non-trivial outliers glimpsed at the outer rim of law-abiding centers of force. "Movements and actions may present many obvious anomalies, breaks, insertions, superimpositions and decompositions," writes Deleuze, but "they none the less obey laws which are based on the distribution of *centers* of force in space" (Deleuze 2013, 128). (Deleuze 2013, 143):

> **…mutation occurs when aberrations of movement take on their independence; that is, when the moving bodies and movements lose their invariants. There then occurs a reversal where movement ceases to demand the true and where time ceases to be subordinate to movement: both at once.** ***Movement which is fundamentally decentered becomes false movement, and time which is fundamentally decentered becomes false movement, and time which is fundamentally liberated becomes power of the false which is now brought into effect in false movement.***

Even if the ordered succession of chronometric time were challenged by overwhelming data density of temporal multiplicity—compelling the inference that temporality were irreducible to chronometric order—temporal multiplicity would be indirectly represented in chronometric subordination to the ultimately orderly moving timeline unconsciously and opportunistically gripped by philosophical and scientific rationalism. The spatial objectification of time through indirect representation is constructed to subordinate time no matter its empirically observed independence from motion in space, as Deleuze expresses: "We can say in general that time is the object of an indirect representation in so far as it is a consequence of action, is dependent on movement and is inferred from space. Hence, no matter how disordered it is, it remains in principle a chronological time" (Ibid. 128).

A common contestation of truth in the 19th and 20th Centuries is to challenge the content of truth, proposing that the content of truth is not temporally and spatially universal, but that its content changes over time and across places, or that truth is relative across cultures. Deleuze problematizes not truth's content but its very form. In the history of thought concerning truth, it is only the true that has a form, while the false has no form. The traditional form of the true is defined by universality, necessity, and eternality. When real states of affairs are represented by true propositions, universal, necessary, and eternal essences are purportedly captured. When images, appearances, and passions cloud mind and body, essences become confused in the translucency of cognition's relations to the real, leading to error—the unformed effectuation of the false. Falsity confuses the real and the imaginary, essence and appearance. When the form of time challenges the form of the true, the false is freed from its subordination to truth, no longer the lacking or confusion of the true. The false is no longer conceptualized as either formed or unformed, but rather as a *power*. Deleuze conceptualizes the power of the false as a power of transformation, of creation. The power of the false creates a new concept of the true, a concept imbued with the form of time: "…contrary to the form of the true which is unifying and tends to the identification of a character (his discovery or simply his coherence), the power of the false cannot be separated from an irreducible multiplicity" (Deleuze 2013, 133).

Poincaré is correctly careful not to draw from his skepticism about temporal concepts and chronometric constructs the conclusion that time does not exist or is an illusion but rather that we have not yet figured out how to conceptualize the nature of time beyond intuition and chronometric convention. Near the conclusion of "The Measure of Time" Poincaré problematizes the relation between temporality and causality (Poincaré 1907, 32):

> **Behold then the rule that we follow, and the only one we can follow: when a phenomenon appears to us as the cause of another, we regard it as anterior. It is therefore by cause that we define time; but most often, when two facts appear to us bound by a constant relation, how do we recognize which is the cause and which is the effect? We assume that the anterior fact, the antecedent, is the cause of the other, of the consequent. It is then by time that we define cause. How [do we] save ourselves from this petitio principii?**

Poincaré's problematization of the subordination, at least the reciprocal determination, of temporality to causality opens a philosophical door to a new conceptualization of their relations, beyond the seemingly inevitable supposition that time is reducible to causal succession—moving from ostensive antecedent to ostensive consequent. The question begged (petitio principii) by the problem, as acknowledged by Poincaré in the last sentence, is constructively engaged in the final two chapters, which attempt to respect causal thinking while conceptualizing evolutionary processes not according to causal laws but rather according to passive and active temporal syntheses (or modes of repetition), effectively delimiting causal thinking to a provisional conceptualization. The powerfully persistent perception of cause-effect relations ineluctably influences thought, and should be respected as such. The challenge of Chapter 4, "The Continuous Variation of Evolutionary Contingency," and Chapter 5, "The Temporal Synthesis of Biological and Evolutionary Rhythms," is to affirm the innovative steps taken by the EES through causal thinking while affirming the deeper and ultimately more pragmatic ways of conceptualizing evolutionary processes—ways more consistent with the problematic structure of the EES. The evolutionary context of causality is troubled by the question posed by Poincaré: "which is the cause and which is the effect"? The key EES concepts of reciprocal causality and constructive development implicitly encounter the question begged, but nowhere in the literature is time explicitly worked out, no doubt due to the disruptive stakes Poincaré points out. Chapter 4 now fully engages the problem of evolutionary causality.

CHAPTER 4. **THE CONTINUOUS VARIATION OF EVOLUTIONARY CONTINGENCY**

Chapter 4 develops the concept of stratigraphic time, which enables understanding of the problematic nature of time as such and how manifold modes of time contribute to evolutionary patterns observed and processes inferred. Stratigraphic time rethinks the deep and developmental temporal rhythms of *evolutionary contingency*, which is determined by assemblages of chance and causal forces. Stratigraphic time challenges irreducibility to the chronometric time and the unidirectional causality of classical idealizations. Stratigraphic time problematizes four commonly assumed lineaments of evolution: (1) a progressive evolutionary arrow; (2) an arrow that is causally deterministic; (3) an arrow actualized incrementally at a gradual rate; (4) as is evident in actual adaptations in current populations. The problematic structure of the EES accommodates the problematic nature of evolutionary time by affirming a variety of deep and developmental tempos, and affirming differential rates as nontrivial sources of direction and pattern in evolutionary history. Understanding the problematic nature of time is necessary for connecting the deep and developmental scales of change, for time is the form of change as such, it is continuous variation. The evolutionary modes of change central to the EES only make sense in the light of time as continuous variation. The concept of stratigraphic time enables understanding of the problematic nature of time as such and how the manifold modes of time contribute to evolutionary patterns observed and processes inferred. Stratigraphic time enables conceptualization of the multiplicity of evolutionary process, driven by a new concept of *evolutionary contingency*. Catalyzed by contemporary discussions of the problem of contingency in evolutionary thought, I argue that the roles of chance and causation in the EES are strengthened by concepts of difference and repetition, akin to the conceptual roles played by arrows and cycles of time in the formation of geological and evolutionary thought.

Chapter 4 first problematizes the causal assumptions and inferences operative in evolutionary theory, specifically the unidirectional causality of the MS, but also the reciprocal causality of the EES. The subordination of time to movement explicated in the third chapter becomes evident as the subordination of evolutionary time to causal movement in the fourth chapter. While the concepts of reciprocal causality and constructive development free causal multiplicity and ontogeny from unidirectional causality and phylogeny, the EES still subordinates evolutionary time to causal movement. The causal multiplicity and reciprocity admit of variable evolutionary rates of stability and modification, but those rates subordinate time itself to their processes, change as such to actual changes. While the concepts of reciprocal causality and constructive development free causal multiplicity and ontogeny from unidirectional causality and phylogenetic determinism, the EES still subordinates evolutionary time to causal movement. The chronometric subordination of time to movement explicated in Chapter 3 becomes evident as the subordination of evolutionary time to causal movement, in Chapter 4. The problematization of the causal assumptions and inferences of the MS and the EES exposes the unconscious opportunism of subordinating evolutionary time to causal movement. In the MS the subordination occurs by way of the subordination of causal multiplicity between evolutionary and developmental processes to unidirectional causation from genetic programming to phenotypic expression, and by way of the subordination of variation to selection. The unconscious opportunism is deeply sedimented in the MS. While the core EES concepts of *reciprocal causality* and *constructive development* free causal multiplicity and ontogeny from strictly unidirectional causality and phylogenetic determinism, the EES still subordinates evolutionary time to causal movement. The causal multiplicity and reciprocity admit of variable evolutionary rates of stability and modification, but those rates subordinate time itself to the fluctuations of processes. Freed from causal movement, evolutionary time becomes an independent and autonomous multiplicity. The concept of *evolutionary contingency* assembles the roles of *chance* and *causality* in the determination of the modes and tempos of time itself in Chapter 4 (Gould 2002, Plotnitsky 2004). The problematic thread of the dissertation affirms the innovative steps taken by the EES through causal thinking while affirming the deeper and ultimately more pragmatic ways of conceptualizing evolutionary processes—ways more consistent with the problematic structure of the EES.

4.1 The Vexed Role of Contingency in Evolutionary Theory

> *I feel most deeply that the whole subject is too profound for the human intellect. A dog might as well speculate on the mind of Newton.*
>
> Charles Darwin (1860)

Science has been characterized as the pursuit of causal patterns. The role of the concept of causality in the sciences has undergone vexed internal variations, losing and regaining its explanatory power. The principle distinction between relations of *correlation* and relations of *causation* is routinely reiterated, and yet vaguely understood, but the conditions for causality are almost always left in abeyance. A common assumption about causality is that while causal *forces* are not directly perceivable causal *relations* may be inferred with validity. Causal truths cannot be read directly from data, no matter the density, they must be indirectly inferred. If inferential validity regarding causal relations is rejected outright then discerning cases of causality from cases of correlation would be impossible (Stamos 2003). Despite the fundamental status of the problem of *causal inference*, the conditions necessary and sufficient to affirm causal relations are either conceptually underdetermined or deferred to the future. Scientists, philosophers of science, and philosophers of nature concerned with the problem of causality perennially turn to the empiricist philosopher

David Hume (1711-1776), in the wake of which a decision must be made about an empirical fact about the interaction between thought and the nature of reality. In *A History of Western Philosophy* (1945), philosopher Bertrand Russell (1872-1970) articulates the problem pressing this decision (642):

> **Hume's real argument is that…we never perceive causal relations, which must therefore, if admitted, be inferred from relations that can be perceived. The controversy is thus reduced to one empirical fact: Do we, or do we not, sometimes perceive a relation which can be called causal? Hume says no, his adversaries say yes, and it is not easy to see how evidence can be produced by either side.**

Russell's adversarial stance became clear long before he wrote the preceding passage in his influential history of philosophy. In *On the Nature of Cause* (1913), Russell proclaims causality obsolete to science, as readily evidenced in the absence of causal concepts in the physics of the early 20th Century:

> **All philosophers, of every school, imagines that causation is one of the fundamental axioms or postulates of science, yet, oddly enough, in advanced sciences such as gravitational astronomy, the word "cause" never appears… To me, it seems that…the reason why physics has ceased to look for causes is that, in fact, there are no such things. The law of causality, I believe, like much that passes muster among philosophers, is a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm.**

Philosopher Frederick Eberhardt's work on causal inference has gone against the critical grain of Russell (Eberhardt 2019, 7:20): "[The] discarding of causality in the first half of the 20th Century has done an enormous amount of harm to the way we think in the sciences … making claims that replace causal notions with ones that are far more ambiguous (e.g. 'linked,' 'results in,' 'lowers,' 'increases probability,' 'strong connection,' 'dependent variables in regression')." Causal inferences are fundamental to evolutionary explanations. Unable to directly observe processes of the past, the evolutionary scientists must draw causal inferences from an imperfect historical record, as well as from contemporary biotic and abiotic variables, which are directly observable, and sometimes via experimental manipulability. Causal processes of the past are inferred according to a more or less rigorous standard of "sufficient similarity" between directly observable causes in contemporary and experimental contexts and indirectly encountered causes of the past stratigraphically preserved in the paleobiological record. The imperfections of the fossil record Darwin deems potentially misleading and consequently detrimental to historical inference, opting instead for indirect yet abundant data from contemporary biotic and abiotic contexts. The introduction to the *Origin* suggests that sufficient confidence in evolution can be achieved by attending acutely to the contemporary conditions of life on earth, by "reflecting on the mutual affinities of organic beings, their embryological relations, their geographic distribution, geological succession, and other such facts" (Darwin 1859, 3). The problem of history and Darwin's methods of historical inference "…set the more general theme underlying both the establishment of evolution as a fact, and the defense of natural selection as its mechanism" (Gould 2002, 99). Prior to explicating and evaluating the avowed causal assumptions of the MS and the EES, the present section examines Darwin's methods of historical inference and how they operate in Darwin's theory, the central causal force of which is of course the mechanism of natural selection. Darwin's *causal minimalism* primes evolutionary theory for 150 plus years of an assumption *of unidirectional causality*, fundamental to the structure and content of the MS, and rivaled in the 21st Century by the EES concept of reciprocal causality.

In the creative hand of Deleuze, Kant's concept of time problematizes the standard concept of truth, the traditional target of philosophy and science, the high stake involved when Poincaré accuses philosophy and especially science of an unconscious opportunism pertaining to the problem of time. Truth making depends on an invariant, merely linear, and measurable concept of time. The power of the false in the wake of time's problematization, its newly acquired status of independence and autonomy, motivates the need for science and philosophy— specifically evolutionary science and philosophy—to relinquish the unconscious opportunism, and to rethink their assumptions, structures, and predictions in relation to a concept of time alive to the independence, autonomy, and multiplicity of temporality. Time and truth have always been intimately related, usually in tension, in the human lineage. Perhaps evolution has not equipped humankind to understand evolution. Perhaps it is more beneficial for our chances to flourish if we do not understand evolution. Avowed philosopher of nature Paul Griffiths' work on "How evolution tracks truth" (2011) facilitates understanding of Deleuze's subtle and counter-intuitive conceptualization of the powers of the false. Griffiths gives an evolutionary debunking argument, not arguing against religious belief, but against the scientific pretention to truth about evolution. Griffiths argues that truth-tracking is only viable for the human species if it is also truth-tracking. It is important to keep in mind that the problem as to whether humans have evolved to track their own evolution is of utmost importance to the problematic approach taken to the nature of time and the nature of evolution. Darwin was acutely aware of such a problem, motivating the formulation of "methods of historical inference" capable of securing the truth of evolutionary process. The following section explicates these methods and how they shape Darwin's theory.

On the Origin of Species concludes with a thought-provoking contrast between gravity, the fixed physical law governing cyclic planetary motion, and the "grandeur" of Charles Darwin's "view of life, with its several powers," with its and facilitated variations amid the aberrant movements of the earth, where fixity founders over deep and developmental time: "whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved" (Darwin 1959). The law of gravity is fixed as true *in all times and in all places*, as universal and necessary, according to an ancient and still widely operative conception of truth (Aristotle 2008, Plotinus 1966, Deleuze 1994, Smith 2013). Laws are treated as invariant in theoretical frameworks, characterized by a spatiotemporal immutability in stark contrast with the chance and facilitated variation evolutionary biologists observe of the mutable earth. The laws determining physical processes are composed of mathematical relations, expressed in equations, such as the electromagnetic field descriptions James Clerk Maxwell articulates in his famous equations, or Albert Einstein's equations describing the dynamics of gravitational forces and fields. The laws of physics are purportedly infinitely precise mathematical statements universally applicable over space and time. Laws of nature exist upon a plane of temporal and spatial invariance. The precise formulations of physical laws are elegant, experimentally repeatable (thus also "falsifiable"), and easily applicable to new cases (strong predictors).

In their influential introduction to the philosophy of biology, *Sex and Death* (1999), Kim Sterelny and Paul Griffiths analyze and evaluate the various roles laws of have played in evolutionary theory, concluding that "though some features of life are predictable from general laws of physics, chemistry, biomechanics, and the like, many are not" (Sterelny and Griffiths 1999, 296). Laws in the traditional sense do not play a fundamental role in biology, and their absence has not inhibited progress in biological fields, which has been impressive over the past 75 years (Godfrey-Smith 2014). Biological generalizations are specific to space and time. Like physical laws, they are idealizations of a multiplicity of non-trivially different causal parts, processes, and relations. 'Laws' are commonly, if tacitly, taken to be observationally induced patterns of interaction between parts, processes, and relations, which are open to change in the future. These patterns arise from a multitude of interactions between incomprehensible structures of nature. Hence biological or evolutionary laws are heuristics for assembling patterns in these parts, processes, and relations. For instance, the processes central to the variegated mechanism of natural selection are not conducive to a description composed by eloquent equations. Darwin's abstract descriptions of the processes are nevertheless as important and often as applicable as laws, even if they remain open to change in ways that traditionally posited laws do not.

4.2 Law-like Evolutionary Explanations

The subordination of time to movement explicated in the second chapter becomes evident as the subordination of evolutionary time to causal movement in the third chapter, not just of unidirectional movement, but also of reciprocal movement. While the concepts of reciprocal causality and constructive development free causal multiplicity and ontogeny from unidirectional causality and phylogeny, the EES still subordinates evolutionary time to causal movement. The causal multiplicity and reciprocity admit of variable evolutionary rates of stability and modification, but those rates subordinate time itself to their fluctuations. The core concepts of *reciprocal causality* and *constructive development* are improved by *origin* and *distribution* explanations (Neander 1995, Godfrey-Smith 2009, 2014), two modes of causal reasoning capable of productively reconfiguring the ultimate and proximate explanations of the MS for the sake of integrating 80 years of research strongly indicating causal complexities within and between evolutionary and developmental strata of explanation (3.4). The new explanatory framework provides provisional clarity to the causal structure of the EES, but is ultimately incapable of meeting the conceptual demands of the EES, which heeds mounting evidence of the crucial role of contingency in the evolutionary process, implying a multiplicity of temporal modes and continuously varying tempos. The trenchant assumptions of *unidirectional causality* and *gene-centrism* in the MS are parallel to the unconscious opportunism of philosophy and science's subordination of time to measurement (per Poincare), and more deeply to movement (per Deleuze). While the concepts of reciprocal causality and constructive development free causal multiplicity and ontogeny from unidirectional causality and phylogenetic determinism, the EES still s2ubordinates evolutionary time to causal movement. The causal multiplicity and reciprocity admit of variable evolutionary rates of stability and modification, but those rates subordinate time itself to the fluctuations of processes.

Godfrey-Smith's explanatory approach is important to the conceptualization of the structure, implications, and predictions of the EES. The philosophical strength of the core concepts of *reciprocal causality* and *constructive development* is improved by *origin* and *distribution* explanations (Neander 1995, Godfrey-Smith 2009, 2014), two modes of causal reasoning, which facilitate the reconfiguration of the ultimate and proximate explanations of the MS. The explanatory heuristic assists the dissertation's attempt to reckon with the problem of integrating 80 years of research strongly indicating causal complexities within and between evolutionary and developmental strata of explanation. The new explanatory framework provides provisional clarity to the causal structure of the EES, but is ultimately incapable of meeting the conceptual demands of the EES, which heeds mounting evidence of the crucial role of contingency in the evolutionary process, implying a multiplicity of temporal modes and continuously varying tempos. After explicating the problematization of evolutionary temporality and causality in the work of G.G. Simpson and Stephen Jay Gould, which challenges the deterministic preeminence of natural selection and gene-centrism, the section turns to Arkady Plotnitsky's critical and reconstructive engagement (2004) with Gould's *The Structure of Evolutionary Theory* (2002). "There could be no Darwin," echoes physicist, cultural theorist, and philosopher of science Plotnitsky, "without contingency anymore than without history, as Darwin's concept of history is itself crucially shaped by the concept of contingency as the interplay of chance and causality (without ultimate causes) in evolution" (Plotnitsky 2004). Plotnitsky produces a concept of *evolutionary contingency* in a more philosophically insightful and physically rigorous fashion than previous conceptualizations of the interaction between *chance* and *causality*, or *discontinuity* and *continuity*, in evolution. Plotnitsky explores the interaction in dialogue with Gould, but also through classical and nonclassical physics.

Evolutionary contingency conceptualizes how the modes and tempos of time itself, as continuous variation, are actualized to form the evolutionary-developmental history chronicled and archived by salient sciences. The concept of evolutionary contingency is apt to illuminate the assumptions concerning the roles of causality and chance operative in the EES, shining light on the subconcepts of *chance variation* (Beatty 2010) and *facilitated variation* (Kirschner and Gerhart 2010) already developed by proponents of the EES. The multiple components of evolutionary contingency are explicated and assembled in the third section. Classic and contemporary problems of chance variation and chance's role in evolutionary explanation are the topics of the fourth section. The relatively novel problem of facilitated, or biased, variation is the topic of the fifth section.

Critically aware of the breakdown of Mayr's dichotomy, Godfrey-Smith (2009, 2014) and others (Neander 1995, Sterelny 2003) have created a new conceptual assemblage apt to provisionally assist in clarifying and specifying the causal reciprocal processes between classic evolutionary vectors and constructive developmental vectors. *Origin* and *distribution* explanations reconfigure ultimate and proximate explanations for the sake of accommodating new research strongly indicating causal complexities between within and between evolutionary and developmental levels of explanation. These explanatory modes are "law-like" in that they attempt to capture, if only provisionally, the causal processes involved in the evolutionary process without claiming these "laws" invariant or immutable in all times and all places. While law-like *origin explanations* and *distribution explanations* are indispensable to evolutionary biology, the diverse enterprise of biology has achieved immense success in the last 75 years without *fixed laws* (Neander 1995, Sterelny and Griffiths 1998, Godfrey-Smith 2009, 2014). The origin-distribution distinction functions with familiarity in the field of evolutionary biology, but it is viable in a variety of domains, including cultural and otherwise non-organic domains. While it has functioned through myriad frameworks in a multiplicity of fields, Karen Neander (1995) and Godfrey-Smith

(2009, 2014) have clarified and strengthened the explanatory distinction as it functions in evolutionary biology. The distinction's multidisciplinary flexibility of applicability makes it apt for the problem agendas of the EES. Folded into the concepts 'origin' and 'distribution' are deeper assumptions concerning temporality, however, and therefore raise critical questions.

In evolutionary biology, origin explanations explain the advent of new variants, how they come to exist in a population. Distribution explanations explain the course of their becoming, what happens between their advent and end. Distribution explanations explain how variants of a population change over time, how they affect and are affected by other variants, and how they are inherited over generations. Affective interactions determine the frequency of variant *A* relative to variant *B*. In the history of evolutionary theory, mutation has typically played the role of origin-explainer while selection has typically played the role of distribution-explainer. Godfrey-Smith suggests that origins and distributions do not form a simple two-step sequence of events—origination through mutation and then distribution through selection—but rather an autocatalytic cycle of cumulative processes, in which variation and selection interact over phylogenetic and ontogenetic scales of time. Godfrey-Smith makes the case that selection does not function merely as a sieve, as modeled by de Vries (1908) and many other theorists, but also as an amplifier. As an amplifier, selection takes on an undeniably nontrivial role in origin explanations, as cumulative selection facilitates the origination of new variants via intermediary variants—if *C* is more likely to originate from *A* when there are more *B*s in existence, then such intermediary production via amplification will play a determinative role in the origin of *C*. Selective regimes of not only filtration but amplification do not directly produce changes, do not themselves determine new variants through mutation, but rather favor future directions of variation through filtration, recombination, amplification, and stabilization. In other words, these are processes of distribution making some mutations more likely than others, but without producing these mutations in one generation change. Mutations can be guided by regimes of selection, but are never themselves produced by regimes of selection. Directed change over generations of individuals and populations are guided by 'arrows of time,' as contingent selective regimes legitimately active in lineages. The passive synthetic role of selection via distributive filtration interacts with the active synthetic and originative role of selection (as amplification). "If there is no process where the results of selection feedback on *another* round of variation, there is no role for selection in explaining the origination of new structures" (GodfreySmith 2009, 41). Natural selection itself without mutation can *filter*, *preserve*, and *amplify* already existing variants (de Vries 1901, Simpson 1944, Gould 2002), leading to the likelihood of some variants becoming more likely than others in future generations, but natural selection alone is not a causally originative mechanism. Godfrey-Smith makes the often overlooked point that "selection in Darwin's sense is as much an amplifier as a filter, and it is the amplifying that matters to its creative role" (Godfrey-Smith 2014, 42). Mutation immediately produces new variants, and thus serves as the target problem of origin explanations. Mutation alone causes random variation, without the vectors of selection. Only mutation and selection operating in tandem can create brains and eyes. Nevertheless, "the view that selection is only a distributionexplainer while mutation is an origin-explainer is wrong" (Godfrey-Smith 2014, 41). Distribution explanations assume variants in populations actually exist. They explain why the variants have the distribution within and across populations and generations that they do, and why distributions change. Darwin's distribution explanations are straightforward: a novel variant emerges, and either becomes more widespread with increasing or sustainable fidelity across generations, or it is lost. Gregor Mendel (1822-1884) is widely recognized as the founder of genetics because he formalized thinking about heredity via pea plant experiments between 1856 and 1863. The laws of Mendelian inheritance The *particulate* conceptualization of inheritance was pioneered by botanist and pioneering geneticist Hugo de Vries (1848-1935), who formulated laws of heredity unbeknownst of Mendel's work. The creation of the concepts of *mutation* and *gene* are pioneered by de Vries in *Intracellular Pangenesis* (1889) and *The Mutation* Theory (1901-1903). The former modifies Darwin's concept of *pangenesis* (1868)—ultimately reckoned untenable in a host of critical treatments (see Weismann 1892, Sterelny and Griffiths 1999)—which attempted to explain the inheritance, the process of sexual reproduction, and developmental processes, especially cellular regeneration. Darwin proposed that processes of pangenesis were actualized through the transmission of organic *particles* (he called "gemmules"). *Intracellular Pangenesis* proposes the concept of *pangene*, which botanist, plant physiologist, and geneticist Wilhelm Johannsen (1857-1927) shortened to *gene*, along with its component concepts of *genotype* and *phenotype* (1903, 1905). These laws are problematized and newly conceptualized through the lens of *population genetics* and the evolutionary thinking accompanying it. The work of Fischer (1930), Wright (1931), and Haldane (1932) transformed the locus of evolutionary causality with the particulate conceptualization of the gene, a discrete individual transmitted with integrity across generations.

4.3 Idealizing the Explanatory Target: From Organism to Gene and Back

The genetically determined assumption of unidirectional causality in consensus syntheses of the past exemplifies these subordinations. A central thesis of *The Selfish Gene* is that genes are *replicators*. The concept of replication functions in Dawkins' work as both the direct product of natural selection and the causal fuel of its engine. Some genes are preformed with higher fidelity than other genes. High-fidelity transmission differential endowment (or preformation) of the capacity for high reproductive fidelity and bandwidth in populations. High-fidelity transmission from *generation 1* to *generation 2* involves what Dawkins calls "faithful" replication, whereby *gene x* at *generation 2* is relatively close to identical in pattern to *gene x* at *generation 1*. If genes are replicators then natural selection is competition between active replicators, germ-line genes whose characteristics causally factor in their chances of reproduction. While the concept of the gene is proven an attractive explanatory target to scientists, philosophers of nature, and of science, it has always proven a moving target and remains elusive, as evinced by thriving devate about the difference-making role of the gene in the greater evolutionary picture (Griffiths and Stotz 2013). Coalescence around the classical molecular gene is evident in impactful papers of the 1980s (Kitcher 1982, Rosenberg 1985, Wimsatt 1986).

During the early stages of life, assemblages of replicators construct vehicles, distributors of their copies. The higher the frequency of replication the stronger the vehicles through which they are genetically transmitted. Individual organisms are prominent kinds of vehicles. The organism functions as the primary *unit of selection* in Darwin (1859), and now again in the EES (Laland et al. 2015), but the gene-centered perspective of Williams (1966), Dawkins (1976), and others (Cronin 1991, Dennett 1995), shifted the way mainstream evolutionary theorists and philosophers conceptualized the problem of the primary unit of selection, and whether there was a single unit or multiple units (Okasha 2006, Sterelny and Kitscher 2001, Wilson 2010). Dawkins conceptualizes the subterranean struggle between genetic replicators, the deeper causal competition underlying the more classical struggle of organisms, the transmission systems, the unidirectional vehicle of genetically controlled evolutionary causality. Struggles over deep time between "selfish genes" fuel evolution to generate "gigantic lumbering robots" (Dawkins 1976). The robots are organisms conceptualized as vehicles. The frequently replicated introduction to *The Selfish Gene* (1976) expresses Dawkins' idealized assumptions about evolutionary causality in a memorably metaphorical manner: "We are survival machines—robot vehicles blindly programmed to preserve the selfish molecules known as genes. This is a truth that still fills me with astonishment. Though I have known it for years, I never seem to get fully used to it" (Dawkins

1976, ix). The dissertation argues that Dawkins is so persistently struck with astonishment by the "truth" about selfish genes is because this truth is based on a basic error in historical reasoning. The tacit idealization of unidirectional causality embodies a conceptual error due to fallacious methods of historical inference.

Godfrey-Smith readily acknowledges time as the catalyst of the novelty of his explanations, but does not conceptualize time itself and the nature of temporal processes involved in origins and distributions, leaving these explanations partial. Godfrey-Smith critically extracts a "tacit idealization" of the temporal nature of natural selection in the history of such summaries, which treats "all cases of natural selection as if they occurred in situations in which generations are *non-overlapping* and *synchronized* across the population" (Godfrey-Smith 2009, 22). The idealized concept of the *discrete generation* is convenient for evolutionary disciplines because time is neutralized across evolutionary scales of time, which are assumed to invariantly pass at a constant speed. Only a minority of organisms—including some annual plants, like basil, and many insects—evolve over discrete generations that do not overlap and whose biological clocks are so simple that they are reliably synchronized with high-bandwidth and fidelity across populations. Idealizing the simple temporal traits of the life-cycle of these organisms is detrimental to evolutionary theory, for "a summary that ignores the role of time can only be seen as describing an *imagined simpler relative* of the process of evolution in the majority of cases" (Godfrey-Smith 2009, 23). The process evident in the majority of species is stratigraphic in directionality, not unidirectional. The minority of cases evincing discrete generations from which temporal synchronization can justifiably be inferred from the behavioral patterns of populations, for a minority case might very well wield a force of change greater than major cases. There is no compelling reason to think that pragmatic and parsimonious demands become compromised by the bottom-up approach to the stratigraphic nature of evolutionary process. There is no convincing reason to think that the scientific community concerned with evolution is not capable of a problematic structural conceptualization of the stratigraphic processes involved, which enables the individual disciplines involved to pursue their problems with autonomy.

The idealization is tacit, it is an "unconscious opportunism" (see Chapter 3), and as such often operates without acknowledgement let alone explication or argumentation. The history of the idealization is worth explicating because while it might seem as though this history would be clear and explicitly reconfigured in response to new data and new concepts in evolutionary biology, it operates implicitly and uncritically in the theories and research traditions dedicated to evolution. The error occurs when evolutionary causality is reduced or otherwise confused with "bookkeeping." The tacit idealization of unidirectional causality embodies a conceptual error due to fallacious methods of historical inference. According to the concept of *stratigraphic time* proposed in the introduction and in Chapters 4 and 5, a generation is a like a stratum, composed of sediment from a multiplicity of eras overlapping at differential speeds eluding standard synchronization procedures. The temporal fallacy operating at the heart of the erroneous idealization infers the causal efficacy of genes on the basis of temporal precedence. Like other scientifically driven theories, evolutionary theory suffers from a penchant for ultimate reduction. The technological capture and inferential attention dedicated to gene frequencies indeed enable discernment of evolutionary processes by extracting empirically tractable patterns The fallacious nature of this unconscious idealization is well illustrated by the history of its methodological and conceptual codification. The history of the erroneous idealization picks up where critical explication of the synthesis history of the MS leaves off. The history begins with the work of Williams (1966), Genes are neither units of selection nor causal actors. Patterns of faithful replication are important and instructive cases of evolutionary temporality and causality, but they are not justifiably generalizable to evolutionary as such.

On their accounts, during the early stages of life, assemblages of replicators construct vehicles, distributors of their copies. The higher the frequency of replication the stronger the vehicles through which they are genetically transmitted. Individual organisms are prominent kinds of vehicles. The organism functions as the primary *unit of selection* in Darwin (1859), and now again in the EES (Laland et al. 2015), but the gene-centered perspective of Williams (1966), Dawkins (1976), and others (Cronin 1991, Dennett 1995), shifted the way mainstream evolutionary theorists and philosophers conceptualized the problem of the primary unit of selection, and whether there was a single unit or multiple units (Okasha 2006, Sterelny and Kitscher 2001, Wilson 2010). Dawkins conceptualizes the subterranean struggle between genetic replicators, the deeper causal competition underlying the more classical struggle of organisms, the transmission systems, the unidirectional vehicle of genetically controlled evolutionary causality. Struggles over deep time between "selfish genes" fuel evolution to generate "gigantic lumbering robots" (Dawkins 1976). The robots are organisms conceptualized as vehicles. The frequently replicated introduction to *The Selfish Gene* (1976) expresses Dawkins' idealized assumptions about evolutionary causality in a memorably metaphorical manner: "We are survival machines—robot vehicles blindly programmed to preserve the selfish molecules known as genes. This is a truth that still fills me with astonishment. Though I have known it for years, I never seem to get fully used to it" (Dawkins 1976, ix). The dissertation argues that Dawkins is so persistently struck with astonishment by the "truth" about selfish genes is because this truth is based on a basic error in historical reasoning. The tacit idealization of unidirectional causality embodies a conceptual error due to fallacious methods of historical inference.

4.4 Quantum Evolution: An Intimation of Causal Multiplicity

The MS is often somewhat simplistically characterized as a synthesis Mendelian inheritance, Darwinian evolution via natural selection, and population genetics. Aspects of Darwin's theory are positively employed in the MS while others are jettisoned. While random genetic variation clearly involves contingent forces, and the catastrophic events affecting populations and lineages cannot be denied, the forces of contingency are not direct shapers of evolutionary process, and the events of contingency are too rare to play a major causal role in the evolutionary process. As articulated in the first section, the MS's unwavering affirmation of the preeminent power of natural selection and its unidirectional movement from genetic programming to developmental production precludes constructive developmental processes capable of influencing evolutionary stability and change. Natural selection acts on genetic variants randomly, and thus contingently, generated. Genetic mutations and 4 are generated by random genetic variation within and between populations across temporally invariant generations of organisms.

Developmental processes of bias and plasticity play no causal role in affecting, let alone producing, genetic variation. Directional vectors of increased fitness are causally unrelated to the random directions in which mutations and recombinations actualize. Phenotypic variation is not biased in directionality by genetic variation, but rather by the transgenerational selection of randomly generated genetic variants. Genetic variation is relatively irrelevant in itself to the actualization of evolutionary vectors. The deterministic evolutionary processes fueling the genecentrism of the MS drown out or explain away the power of contingency, thus overdetermining selection and underdetermining variation in the evolutionary process. The MS effectively strips nontrivial forces of contingency out of the unidirectional arrow of evolutionary history emphasized by Gould in the above quotation. Gould found the largely overlooked role of contingency as motivation for a new synthesis, and as a critical concept for the formulation of this expanded framework.

The problem of evolutionary time plays an important role in the early work of G.G. Simpson (1902-1984)—a pioneer of paleontology, and unique evolutionary theorist— culminating in the magisterial *Tempo and Mode of Evolution* (1944), which unfolds a pluralistic perspective on evolutionary causality. The book builds toward a novel approach to microevolutionary explanation of macroevolutionary patterns beyond the range of natural selection, typified by a "most striking and original" concept (Gould 2002, 529). The concept of *quantum evolution* is "perhaps the most important outcome of the investigation [*Tempo and Mode*], but also the most controversial and hypothetical" (Simpson 1944, 206). The controversial demotion of natural selection has been repeatedly misconstrued as an audacious affront on the power of Darwin's mechanism. The explanatory power of natural selection takes on new relation to causal components previously excluded from evolutionary syntheses, thus changing the explanatory role of the mechanism. The conceptual modification of evolutionary causality to include modalities other than natural selection in Simpson's work only minimally challenges the qualification—crucial for Darwin's "one long argument" and for the causal logic of the MS— that natural selection is the *preeminent* force of evolutionary change. The attribution of preeminence from a 21st Century perspective appears radical in its causal and temporal idealizations, which imagine evolutionary time and causality to be simpler than they actually are. The most acclaimed paleontological descendant, Stephen Jay Gould, inherited the problem of discontinuities (or "gaps") in the stratigraphic paleobiological record from Simpson, who did not "explain away" the problem by surrendering to the imperfect sets of fossil remains. This is a difficult theoretical decision for an evolutionist in the early 20th Century, and considering Simpson's strict adherence to gradualism and adaptationism. Forced to affirm the discontinuities as ineluctably influential temporal factors inducing and directing evolution, Simpson must think beyond the concept of gradualistic selection, beyond what evolutionary biologist August Weismann (1834-1914) called the "all sufficiency" of natural selection in the phyletic mode as the preeminent component of evolutionary theory. Quantum evolution expresses what Simpson believed to be "the most dominant and most essential process in the origin of taxonomic units of relatively high rank, such as families, orders, and classes" (Simpson 1944, 206). Simpson even believed that quantum evolution includes cases "that explain the mystery that hovers over the origins of such major groups" (Ibid.).

As a descendant of geology, Simpson affirmed Lyell's principle that "the key to the past is the present" (Lyell), so the key to determining the causal mechanisms of evolution is the study of living populations. As a descendant of Mendel, and more directly by Fischer (1930), Wright (1931), and Haldane (1932), Simpson sought an alternative causal mechanism in the genetic nature of the organisms in living populations constituting species. Simpson's persistent commitment to the proviso that only genetic models of causal mechanisms are sufficient for explaining the macroevolutionary patterns of continuity *and* discontinuity evident in the phylogenetic fossil record. Wright's concept of *genetic drift* resonated with Simpson's commitment and so became the alternative mechanism of microevolutionary causality operating astride, perhaps even in opposition to, but in no way interrupting the operation of, natural selection. Quantum evolution problematizes the preeminence of natural selection, but is nevertheless highly restricted by the causal minimalism of *population genetics*.

Evolutionary theory distinguishes between change caused by selection and change cause by drift. The concept of *drift* fires much debate, but in all cases carries senses of chance, randomness, indeterminacy, and contingency. The quantum evolutionary role of genetic drift function in the major transitions of small populations during "inadaptive phases" (Ibid. 199), unstable milieu transformed into intermediary stages of new adaptive processes. When a lineage traverses from one adaptive peak to another intermediary populations endure adaptive valleys in which quantum evolution propels them as an “all-or-none reaction” (Ibid.). The quantum reaction results in the rapid origination of new phenotypes at high taxonomic strata. Simpson affirmed population genetics sufficient in itself as origin explainer and distribution explainer of the macroevolutionary patterns observationally and chronometrically captured by via the stratigraphic methodology of paleontology. Simpson’s early work affirms adaptation under the selective causal control as the primary form of evolutionary process—the prime force of change—but avowedly rejected “the extreme dictum that all evolution is primarily adaptive” (Simpson 1944, 180). The extreme restriction of evolutionary causality to selection-driven adaptation persists, not only in narrow representations common in relatively unrelated disciplines, and in cultural norms of understanding, but even in evolutionary biology, philosophy of biology, evolutionary psychology, and so on.

Simpson’s theoretical shift during the decade between *Mode and Tempo* and *The Major Features of Evolution* (1953), occurring astride the solidification of the adaptationist idealization in the MS, is a shift from a nonadaptationist conceptualization of intermediate phases priming populations for major transitions to selectionist conceptualization. Along with Dobzhansky and Mayr, Simpson shifted from causal pluralism to causal minimalism—a more sweeping shift in evolutionary theory Gould calls “the hardening” of the MS (Gould 2002, 520). Simpson accordingly disempowers the explanatory role of his prized conceptual creation of quantum evolution, for it “is not a different sort of evolution from phyletic evolution [after all], or even a distinctly different element of the total phylogenetic pattern. It is a special, more or less extreme and limiting case of phyletic evolution” (Ibid. 389). The quantum mode of evolution is now considered *more* strictly determined by selection than any other mode. The concept’s causal role in the phyletic explanation of evolutionary change “moves comfortably under the umbrella of the adaptationist program" (Gould 2002, 531). Genetic drift and other chance-involving forces of evolutionary change were also excluded in deference to the preeminent power of natural selection: "Genetic drift is certainly not involved in all or in most origins of higher categories, even of very high categories such as classes or phyla" (Simpson 1953, 355). "Selection is truly creative force and not solely negative in action" (Simpson 1944, 180). Simpson's early work enabled Gould to challenge two detrimental assumptions operative in the MS: (1) "all phenomena measured in millions of years must be explained by smooth extrapolation from palpable causes on generational scales in modern populations" and (2) "that the paleontological record can therefore only present a pageant of products generated by known causes, and not provide an independent theory or even a set of additional causal principles" (Gould 2002, 521).

4.5 The Intensive Modality of Synthesis

The movements of arrows and cycles involved in the discovery of deep time unconsciously subordinated time to movement. Early evolutionary theory and the MS perhaps unconsciously, though nevertheless far too readily and opportunistically, rely on time's subordination to movement to maintain *a traditional truth targ*et. Even though the concept of time operative in traditional evolutionary thought conflicts with an abundance of evidence accrued by salient sciences and conflicts more deeply with assumptions built into the very fundaments of evolutionary theory, the unconscious opportunism maintains its stranglehold. Letting go of the unconscious opportunism of chronometrically measurable, invariantly passing, and merely linear temporality, not only enables the EES to deepen its commitment to the variability of evolutionary time, it is also enabled to newly conceptualize its most vital explanatory principles of *constructive development* and *reciprocal causality* in order to structure its lineaments in a more philosophically consistent and compelling fashion.

The intensive modality of evolutionary processes face philosophers and scientists with an inevitable "I do not know": "…philosophy and science (like art itself with its third side) include an I do not know that has become positive and creative, the condition of creation itself, and that consists in determining by what one does not know" (Deleuze and Guattari 1994, 128). To the extent that Deleuze's philosophy of time and the extension of Deleuze and Guattari's concept of stratigraphic time are speculative and transcendental, Godfrey-Smith would characterize them as forms of the second approach. Deleuze and Deleuze and Guattari characterize their philosophical activity transcendental empiricism (Deleuze 1994, Bryant 2008). Both transcendental and empirical principles are important to assemblages of evolutionary problems and philosophical concepts. Transcendental empiricism leads the philosopher "beyond the state of experience toward the conditions of experience. But these conditions are neither general nor abstract. They are no broader than the conditioned: they are the conditions of real experience" (Deleuze 1988, 27). "Empiricism truly becomes transcendental…only when we apprehend directly in the sensible that which can only be sensed, the very being of the sensible: difference, potential difference, and difference in intensity as the reason behind qualitative diversity" (Deleuze 1994, 56). An intensity is a singularity within a virtual system of differential relations with corresponding degrees of variation. Each intensity is to some degree connected to the unconscious transcendental field of intensity, which constitutes the qualitative differences of sensibility. Intensities are imperceptible, insensible to use Darwin's concept. They are nevertheless "sensed" inasmuch as the unconscious sensibility is "awakened": "It is intensity or difference in intensity which constitutes the peculiar limit of sensibility. As such, it has the paradoxical character of that limit: it is the imperceptible, that which cannot be sensed because it is always covered by a quality which alienates or contradicts it, always within an extensity which inverts and cancels it" (Deleuze 1994, 236-7). Intensity is the limit of sensibility, extinguishing itself in qualitative and quantitative differences. The problem of intensity is that extensity cannot explain the individuations actualizing within them. The concept of intensity is so crucial that Deleuze conceptualizes as follows: "the sufficient reason of all phenomena, the condition of that which appears" as difference of intensity (220).

The problematic structure of the EES accommodates the problematic nature of evolutionary time by affirming a variety of deep and developmental tempos, and affirming differential rates as nontrivial sources of direction and pattern in evolutionary history. Understanding the problematic nature of time is necessary for connecting deep and developmental scales of change, for time is the form of change as such, it is continuous variation. The evolutionary modes of change central to the EES only make sense in the light of time as continuous variation. The concept of stratigraphic time enables understanding of the problematic nature of time as such and how the manifold modes of time contribute to evolutionary patterns observed and processes inferred. Stratigraphic time enables conceptualization of the multiplicity of evolutionary process, driven by a new concept of *evolutionary contingency.* Catalyzed by contemporary discussions of the problem of contingency in evolutionary thought, I argue that the roles of chance and causation in the Extended Evolutionary Synthesis are strengthened by concepts of difference and repetition, akin to the conceptual roles played by arrows and cycles of time in the formation of geological and evolutionary thought. These critical and constructive arguments are guided by Gilles Deleuze's philosophy of time, which he conceptualizes under the rubric of *repetition.*

For the MS, macroevolutionary patterns explicate microevolutionary processes in a temporally smooth and causally unidirectional modality. For the EES, macroevolutionary patterns of change are consequents of microevolutionary processes *but also* causal antecedents of the latter. Macroevolution is not only an emergent pattern but an active assemblage of causal modes reciprocally producing microevolution. The problematization of the causal assumptions and inferences of the MS and the EES exposes the unconscious opportunism of subordinating evolutionary time to causal movement. In the MS the subordination occurs by way of the subordination of causal multiplicity between evolutionary and developmental processes to unidirectional causation from genetic programming to phenotypic expression, and by way of the subordination of variation to selection. The unconscious opportunism is deeply sedimented in the MS. While the concepts of reciprocal causality and constructive development free causal multiplicity and ontogeny from unidirectional causality and phylogeny, the EES still subordinates evolutionary time to causal movement. The causal multiplicity and reciprocity admit of variable evolutionary rates of stability and modification, but those rates subordinate time itself to their fluctuations. Chapter 2 articulated the liberation of time from movement initiated in the work of Kant and continued by thinkers after Kant, especially Deleuze. Freed from causal movement, evolutionary time becomes an independent and autonomous multiplicity. The concept of evolutionary contingency is apt to illuminate the roles of causality and chance operative in the EES, and effectively conceptualized by philosopher John Beatty's work on *chance variation* (2010) and the concept of *facilitated variation*, created by cell and molecular biologists Marc Kirschner and John Gerhart (2010). Plotnitsky develops the concept of evolutionary contingency Plotnitsky explores the interaction in dialogue with Gould, but also through classical and nonclassical physics. Gould's concept of contingency is multifaceted, acting at and across multiple levels (or tiers) of the evolutionary process. Contingency in evolutionary theory has traditionally and still typically refers to the chance (or random) variation at the genetic level, to chance variants subject to selection. John Beatty is an EES engineer focused on the differences between chance and *directed* variation. Beatty traces the important status of chance variation in evolutionary theory from Darwin to the MS, showing how chance variation has been variably subordinated to natural selection. Beatty argues that the concept of chance variation was initially created for the sake of its subordination to natural selection. TBC Plotnitsky's approach to the problem of configuring contingent forces and deterministic forces in the evolutionary process hinges on the joint role of *chance* and *discontinuity*. Plotnitsky writes of the *role* of chance as to chance itself in resonance with Gould's insistence that despite the importance of chance as a contingent force his reconstruction of evolutionary theory (2001) is not foremost concerned with chance, but rather with "My appeal to contingency stresses the significance of theorizing chance in evolution, as opposed to causal explanation, while keeping the latter as part of the overall theory." Chapter 5 conceptualizes evolutionary contingency through the passive and active temporal modes of repetition.

CHAPTER 5. **STRATIGRAPHIC TIME: THE SYNTHESIS OF BIOLOGICAL AND EVOLUTIONARY RHYTHMS**

The fifth and final chapter conceptualizes the stratigraphic assemblage temporal of biological rhythms and evolutionary rhythms. Explication of the uncritical subordination of time to movement operative in philosophy and science enables evaluation of the problem of evolutionary time in its various subordinations to evolutionary process. Gilles Deleuze's *Difference and Repetition* conceptualizes time under the rubric of repetition, as non-metric and non-chronological manifold of passive and active syntheses. Deleuze's syntheses of time are forms of repetition, and their transcendental role in Deleuze's philosophy of time provide a defense of "Repetition for Itself"—the title of the second chapter of the work—whereby the paradox of the sameness and difference of any given repetition is explicated in terms of time, serving as a formal case of the paradox. The three types of passive syntheses are as follows: (1) habit, which 'prioritizes' the present, what Deleuze calls the *living present*, as contraction of the past; (2) memory, which prioritizes the past as the pure fullness of any given present, in a bifurcating relation of coexistence with the present, enabling it to pass (or flow); and (3) the new, which prioritizes the future, and refers to the productive processes of temporality. The irreducible modalities of metamorphosis are asymmetrical temporal syntheses coexistent upon a plane of continuous variation. The temporal syntheses do not work on continuous variation itself but rather on the variations actualized through the modes and tempos of continuous variation. The difference in kind between time and the temporal multiplicity of various disciplinary strata is a problematic intrinsic to the construction of stratigraphic time.

5.1 Chronobiology: The Power of Movement and Measurement

The 2017 Nobel Prize in Physiology or Medicine was jointly awarded to Jeffrey C. Hall, Michael Rosbash, and Michael W. Young for "their discoveries of molecular mechanisms that control circadian rhythms," ubiquitous clock-like biological processes facilitating life in our little niche of the universe (Nobel Assembly 2017, Ibáñez 2017, 1). The molecular mechanisms of circadian rhythms modeled by Young, Hall, and Rosbash make a compelling case that the temporal patterns of myriad forms of life—from bacteria and fungi to plants and animals—are not regulated via *exogenous* signals, such as sunlight, atmospheric conditions, predators and prey. The novelty of their research is in showing how circadian rhythms are *endogenously* regulated (Nobel Assembly 2017, Ibáñez 2017). Circadian rhythms are not the only modes of biological timing characteristic of organisms, but evidently the most repetitious and most observable on earth. "There are other ways to reset a biological clock," writes Winfree, "but the vast majority of living organisms have adopted the daily event that recurs most readily—the alternation of light and darkness—as the event to which their circadian clocks respond most sensitively" (Winfree 1987a, 48). The rhythmic expressions of the earth pulsate through a multiplicity of oscillatory processes in relation to the rhythms of the solar system, as eloquently articulated by leading biological rhythm researcher Michael Young in *The Metronomic Society*: "Every bodily process is pulsing to its own beat within the overall beats of the solar system" (Young 1988, 20). Active in most cells, contemporary biologists consider circadian rhythms the foremost observable organismic processes on earth, thus serving as the prime example of biological rhythms. Circadian oscillation habits in organisms ranging from protozoa and algae to insects and animals differentially determine patterns such as cell division, photosynthesis, and physical movement.

The qualification of approximation (to e.g. 24 hours) characteristic of circadian rhythms might seem to imply imperfection, low synchronization fidelity between the organism's rhythms and the rhythms of the solar system, but the temporal discrepancy between organismic oscillations and environmental oscillations indicates circadian plasticity, an evolved capacity for living with change. It is thought provoking to note, as a testament to the plastic and transformative nature of circadian rhythms that approximately 600 million years before present, day length was approximately 21 hours in duration, ticking the 420 day duration of the year (Saunders 1977, 9). The qualification implies variance between individual bodies found within a single species. Even within a single population, the rhythms of bodies are only loosely synchronized, in fact frequently in tension. A body's temporal rhythms differ from other bodies, but also differ amongst themselves within an individual body, for multiplicities of rhythms, which are sometimes in conflict, assemble through patterns beating in only relative and transient synchrony, striking in syncopation differently during different periods of a body's life (Deleuze 1994, 31-33). A body is an assemblage of different processes always in flux yet synthesized to individuate an active form of life. The syntheses determine the oscillations of organisms on earth, oscillations always subject to change. The time-keeping rhythms of multicellular processes passively and actively synthesize a multiplicity of rhythms to determine the observable temporal patterns attributed to bodies. Chronobiologists aimed for decades to determine the mechanisms capable of synthetically processing a body's multiplicity of rhythms, beating in variation.

The prolific work of 20th Century mathematical biologist and pioneer of biophysics, Arthur Winfree, is dedicated to time, demonstrating through rigorous experimentation and geometrical modeling how biological rhythms not only repeat temporal patterns of the pat but also periodically break those patterns. The cyclic patterns evincing continuity attest to the pervasive power of repetition at all levels of life, but the profound implications of Winfree's work, and that of many others, follow from the function of breakage, or resetting, of such cycles, which entails the necessity of difference-making processes—a testament to the pervasive power of difference.

Winfree conceptualizes rhythms in terms of the continuities and discontinuities of spatiotemporal dynamisms. Winfree's magisterial magnum opus, *The Geometry of Biological Time*, "is a story about dynamics: about change, flow, and rhythm, mostly in things that are alive…but not about all kinds of dynamics. It is mostly about processes that repeat themselves regularly. In living systems, as in much of mankind's energy-handling machinery, rhythmic return through a cycle of change is a ubiquitous principle of organization. So this book of temporal morphology is mostly about circles, in one guise after another" (Winfree 2001, xxiii).

The first half of *The Geometry of Biological Time* explicates main themes through a scheme of "fundamental concepts," featuring rhythm, bifurcation, oscillation, synchronization, and especially phase, with its spaces, transitions, singularities, and rings (Winfree 2001, xxiv). Winfree calls the second half a "*dramatis personae*," in which the fundamental concepts specify organismic time-keeping mechanisms, such as pacemaker neurons, slime-mold amoebae, circadian rhythms, the cell mitotic cycle, etc., and model nonliving experimental systems.

Winfree models myriad time-keeping mechanisms in biology through experimentation with *clocks* and *maps*, two longstanding metaphors within the history of science (Gallison 2003 carefully explores this history in *Einstein's Clocks, Poincare's Maps*). Temporal clocks and maps share two inextricably interactive components, continuity (or smoothness), and discontinuity (or periodicity). The dynamic interplay between these components is highly variable, from one lifeway to the next, and changes in mode and tempo over various scales of time. Chronobiology attests to the variability of earth's rhythms (Glass and Mackey 1988). Winfree's work concurrently catalyzes and criticizes chronobiology, particularly criticizing canonical chronological biases toward continuity and invariance, neglecting the crucial role of discontinuities, by affirmatively configuring non-chronological processes of biological rhythms through experimental and observational data and modeling. Winfree demonstrates how nonchronological processes are not anomalous and derivative qualities of the modal and temporal dynamics of biological rhythms, but rather necessary processes of transformation upon which the phases of rhythmic continuity depend. Repeatedly demonstrated temporal discontinuities are unavoidable observables in contemporary sciences salient to biological rhythmicity. Synchronized movements of mechanical clocks, and other chronometers, cannot capture biological rhythmicity because the periodic discontinuity of the resetting process of the temporal cycles of biological rhythms evade measurement.

The periodic resetting of the orchestra of rhythms assembling an organism evinces the fundamental nature of *variation* and *plasticity* in relation to selection and bias. The periodic resetting of the orchestra of rhythms assembling an organism evince the fundamental nature of variation and plasticity in relation to selection and bias. Winfree accrued enormous empirical support for the nontrivial role of temporal discontinuity. Not only is the role of time's breakdown nontrivial in relation to the more readily classifiable temporal continuities of biological rhythms, the breakages are in a relation of reciprocal determination with them. Without the rhythmic plasticity to change, a rhythmic pattern is of little worth to an organism (Winfree 1987a, 47):

> **A clock is not much good if you can't pull out its stem and reset it. An uncorrectable biological clock would be almost useless unless the match between its period and that of the earth's rotations were perfect. Still, even if the clock were immune to disturbance by fevers or cold or hot weather and remained unperturbed during intervals of emotional and hormonal upset, there would inevitably be some small discrepancy between the internal and external periods.**

Circadian resetting is not the only mode of transformation common to the biological rhythms of organisms, but it is evidently the most repetitious on earth: "There are other ways to reset a biological clock, but the vast majority of living organisms have adopted the daily event that recurs most readily—the alternation of light and darkness—as the event to which their circadian clocks respond most sensitively" (Winfree 1987a, 48). Synchronized movements of mechanical clocks, and other human chronometers, cannot capture biological clocks because the periodic resetting capacity of the temporal cycles of biological rhythms evade chronometric measurement. Winfree's

When Time Breaks Down demonstrated the necessity of ruptures in biological time's cycles (1987b). The major thesis of the work predicts that phase transitions of biological rhythms are potentially precipitated by minute perturbations of the pattern, given certain conditions. Winfree demonstrated the thesis by employing topological strategies from the mathematics of shapes and surfaces. Heart arrhythmias serve as the focal example set of conditions.

When Time Breaks Down uses the concept of timelessness to explain the necessity of resettable plasticity in any given clock (cellular, neural, cultural, atmospheric, etc.). Provoked by perturbance of rhythmic fidelity, timelessness is the milieu through which a process changes phases. Topologically ineluctable *phase singularities* break time symmetries and other cyclic patterns. Every breakage of temporal rhythmicity is a *singularity*. These discontinuous events of singularity are topologically necessary for any continuous time-keeping mechanisms. The ostensibly independently functioning time-keeping rhythms of multicellular processes passively and actively synthesize assemblages of rhythms to determine the observable temporal patterns attributed to organisms. The syntheses determine the oscillations of organisms on earth, oscillations always subject to change according to the necessity of timelessness. Winfree's term *timelessness* is philosophically burdensome for reasons here left in abeyance, but the term generally obscures more than illuminates a major breakthrough. Reaching beyond terminological differences, one can clearly grasp the concept's innovative aim to articulate the paradoxical process of breakdown entailed by the discontinuous transition of phase entrainment when a rhythm changes its temporal orientation (e.g. to the light of the sun over seasons). The focal concept of entrainment refers to "the linked synchrony of any repeating cycles" actualizing as biological, or nonbiological, patterns of relation (Tomlinson 2015, 77). "In whatever realm they occur, all instances of entrainment share two basic features: the presence of two or more cyclical phenomena—oscillators is the term of art—and their linked interrelationship" (Ibid.). Entrainment requires flexibility and the capacity for rhythmic resetting. Breakages are enabled by rhythmic plasticity, a developmental pliability tuned to the frequent pressure to reset biological clocks, to transform habits to more effectively interact with changing circumstances, to meet the advent of the new with newly assembled rhythms. The phase precariousness of biological rhythms indicates the evolutionary benefit of developmental plasticity, which together works across stratigraphic scales of inheritance and constructive contingency with developmental bias in the EES.

The perpetual advent of breakages and new assemblages undergo what in thermodynamics are called *phase transitions*, a tradition employed by Winfree, studied by Deleuze and Guattari, and elaborated by philosophers influenced by the latter (e.g. Bell 2006, Delanda 2002, Protevi 2013). The fluctuating discrepancies between rhythmic genetic, physiological, or behavioral patterns and tidal, lunar, geological, and other such rhythms evince a kind of circadian plasticity facilitating phase transitions. *Phase* is perhaps the keystone concept for research concerning biological temporality, referring to a position on a circle: "Phrase provides us with a banner around which to rally a welter of diverse rhythmic (temporal) or periodic (spatial) patterns that lie close at hand all around us in the natural world" (Winfree 2001, xxiii). Phase transitions are necessary for the persistence of patterned passive and active processes. The patterns change to continue patterned persistence through changing conditions. The temporal nature of such change in evolutionary biology is irreducible to thermodynamic arrows of time. The timing of evolutionary change in part two will be conceptualized through the work of recent philosophy of nature in combination with the biologically informed work of Deleuze and Guattari. Deleuze explicates the spatiotemporal dynamics of a multiplicity of rhythms and their relations of breakage and assemblage through his work on the passive and active syntheses of time.

The *screw-like* temporal discontinuity involved in biological rhythms is a sensitive topic to broach in the sciences, as evinced by Winfree's cantankerous relationship with the disciplines involved in his groundbreaking research. While temporal discontinuities aren't always determinative of physical processes, they are unavoidable observables at this point in pertinent sciences, and not only that, but crucial pieces of the evolutionary puzzle in the wake of a halfcentury of rigorous work in the earth and life sciences. "In some cases, the discovery of this screw-like discontinuity constitutes only a trivial insight into the physical mechanisms involved. In some cases, it constitutes a more profound insight, which would be difficult to arrive at in any other way. And in some cases, it has little to do with mechanism but rather points to a fundamental limitation in the process of measurement" (Winfree 2001, 29). A driving force of the first half of the proposed dissertation is the need to conceptualize temporal discontinuities freed from movements available to measurement. Concepts are not confined by current mechanisms of measurement, and able to configure discontinuous temporal processes by thinking beyond descriptions of temporal processes extrapolated from the laws of classical physics. As discussed just below, biology has always needed to dig deeper than invariant laws to accommodate the empirical exigency of infinite variation. Evolutionary biology must merge with the constructive resources of philosophical concept creation to encounter ambiguities and paradoxes concerning evolutionary time, for "if we insist upon forcing nature into a description in terms of phases, we may encounter ambiguities, even paradoxes, implicit in the very definition of that observable because there are situations in which phase is ambiguous or can only be defined by admitting ghastly discontinuities into the description of our observations" (Ibid. 30).

Focusing on *cyclic* processes, their rhythmic continuities and discontinuities over developmental time, Winfree suspends questions concerning the *arrows* of biological temporality over deep time, the directional vectors of biological rhythms via evolutionary and developmental processes. Questions concerning arrows of biological time ineluctably encounter what Winfree considered "a fundamental mystery" (Winfree 1987a, 160, cf. Coveney and Highfield 1990, 301), calling for our attention: “Though we cannot account for this rhythm, neither can we silently bypass such a fundamental mystery.” If the molecular mechanisms controlling such rhythms have been discovered (Nobel Assembly 2017, Ibáñez 2017), the evolutionary drivers remain undiscovered absent conceptualization of evolutionary time and change. There is an absence of compelling reasons for the evolution of circadian rhythms, and other such biological rhythms, as admitted by Winfree in *The Timing of Biological Clocks*, where he tentatively floats three viable candidate evolutionary explanations for their existence, telling three “stories” about the advent of the temporal habits. “The first story turns on a timing system designed to overcome the disruptive effects of sunlight on the delicate machinery of the cell. The second story focuses on an early cell’s daily cycle of activities, imposed at first only by the daily cycle of light and dark, warmth and cold. A third starts with an imaginary primitive cell metabolizing steadily in a constant environment, and asks how stable that steadiness could be, even without the impact of sunrise and sunset” (Winfree 1987a, 161).

5.2 Preformism: The Retrospective Movement of the True

Deleuze problematizes two habits of evolutionary thought, two misconceptions: (1) evolutionary causality is best conceptualized as the realization of possibilities, and (2) evolutionary causality is reductively determined as interaction between pure actuals (Deleuze 1988, 98). The first misconception is exemplified by *preformism* and the second misconception is exemplified by what has been called *actualism* (Delanda 2002, During 2016). Preformism assumes that a fixed form or sequence (e.g. a DNA blueprint for a genetically inherited phenotypic program) preexisting its actualization causally determines the development of the embryo or organism, and perhaps even entire populations. Preformism supposes that the possible contains the realizable or determinable actuals of the future in advance of their actualization or the determination of their reality. An immediate consequence of the assumption that preformed patterns or sequences of identity predetermining the production of organismic lifeways is the preclusion of the production of differential and non-trivial novelty. The problem of novelty is closely connected to the problem of causality. Preformism suffers from an idealized causality of strict linearity—the reduction to succession discussed above—whereby allegedly isolatable causes determine isolatable effects in an ordered sequence of connected instants passing invariantly. Despite the increasing acknowledgement of causal multiplicity contemporary kinds of preformism populate evolutionary debate. If effects pre-exist in their causes, novel variation is relegated to secondorder differences of quantity, ascribed the status of arbitrary aberration from the norms, and thereby rendered causally inconsequential to the course of evolution. As articulated in the second section, the causal minimalism of unidirectional determination driving the MS is a kind of preformism. Deleuze's philosophy of repetition as passive and active temporal synthesis (1994) is capable of conceptualizing evolutionary repetition in ways that constructively reconfigure the all too simplistic assumption concerning repetition that governs thought about the causal multiplicity of processes constitutive of inheritance. "The idea of the possible appears when, instead of grasping each existent in its novelty, the whole of existence is related to a preformed element, from which everything is supposed to emerge by simple 'realization'" (Deleuze 1988, 20). The detrimental confusion between *possibility* and *virtuality* is the source of obscuration for philosophers of nature, philosophers of science, and scientists. If "evolution takes place from the virtual to actuals" (Deleuze 1988, 98) then the phenomena observed and chronometrically organized by science closes itself off from the virtuality of evolutionary process, resulting in a *causal minimalism* Godfrey-Smith 2006, 2) whereby the three fundamental lineaments of time are reduced to only one, that of *succession*. The reduction distorts the nature of evolutionary time by tacitly eluding or explicitly excluding *coexistence* and *novelty*.

5.3 Actualism: The Reduction of Evolutionary Time to Causal Succession

Actualism is oblivious to the *intensity* of the actualization of the phenomenal instants organized into sequences. "Individuation is the act by which intensity determines differential relations to become actualized" (Deleuze 1994, 246). Deleuze's account of intensive individuation and differenciation describe "an intensive field, are populated not with kinds or types, but divergent lines and thresholds of variation" (Roffe 2019, 48). Actualization is a multiplicity of differential rhythms. The changes differentially connecting evolutionary and developmental rhythms repeat in a non-standard fashion. The inheritance of x from generation 1 to generation 2 involves a degree of fidelity high enough to warrant an inference that 1x is still x in 2, despite a degree of variation from 1 to 2. The evolutionary aspects of the processes involved in the transmission of x consist in *differenciation* of the units of inheritance. This principle of non-repetition, or of continuous temporal differentiation implies indetermination and novelty, which are perpetual consequences of the continuous preservation of the past pressing the present, together with the contractive capacity of the living present to perpetually modify the past into the future, to differentiate. Time is always opening new futures. Just as the (pure) past is not a container of past presents, a pool of accumulating actuals, the future is not composed of whatever events come to pass—it is not made of future actuals.

"Darwin's great novelty, perhaps," Deleuze suggests with caution, "was that of inaugurating the thought of individual difference. The leitmotiv of *The Origin of Species*: we do not know what individual difference is capable of! We do not know how far it can go, assuming that we add to it natural selection" (Deleuze 1994a, 248). One might well disagree with Deleuze's suggestion, after all, the novelty of Darwin's work is more often identified as the establishment of evolution as a fact, the argument for natural selection, survival of the fittest, the rationalist postulate of gradualism, etc. Regardless of whether Deleuze's leitmotiv suggestion strikes one as plausible or not, the importance of individual difference and the nature of its determination is undeniable. Deleuze construes natural selection as individual difference and the differenciation of difference, which "plays the role of a principle of reality, even of success, and shows how the differences become connected to one another and accumulate in a given direction, but also how they tend to diverge further and further in different or opposed directions. Natural selection plays an essential role: the differenciation of difference (survival of the most divergent)" (Deleuze 1994a, 248). The intensive processes of stratigraphic temporality are concealed by extensive actualizations, appearing as causal minimalism in the MS and causal multiplicity in the EES.

An *empirical principle* is an "instance which governs a particular domain. Every domain is a qualified and extended partial system, governed in such a manner that the difference of intensity which creates it tends to be cancelled within it (*law of nature*)" (Deleuze 1994a, 241). A *transcendental principle* "does not govern any domain but gives the domain to be governed to a given empirical principle; it accounts for the subjection of a domain to a principle. The domain is created by difference of intensity, and given by this difference to an empirical principle according to which and in which the difference itself is cancelled" (Ibid.). "Only transcendental enquiry can discover that intensity remains implicated in itself and continues to envelop difference at the very moment when it is reflected in the extensity and the quality that it creates, which implicate it only secondarily, just enough to 'explicate it'" (Deleuze 1994a, 240). "Every intensity is differential, [and] by itself a difference," for intensity is the form of difference in so far as this is the reason of the sensible. … The reason of the sensible, the condition of that which appears, is not space and time but the Unequal itself, disparateness as it is determined and comprised in difference of intensity, in intensity as difference" (Deleuze 1994a, 222-3). The extensive expression of intensive forces reckon the latter insensible. The insensibility of the incremental nature of evolutionary change ensures empirical evasion. The insensibility if evolutionary process is constructively conceptualized as *intensity*, a transcendental approach to the extensive expression of intensive processes, which effectively hides the intensive processes in their actualization. The intensive processes of evolutionary actualization through differenciation are inaccessible to sensory and technical observation, but they are accessible to thought.

The stratigraphic temporality of adaptation compels a conceptual heterogenesis of adaptation. Deleuze's first temporal synthesis, or mode of repetition, which features the core conceptual component of *habit*. The passive syntheses of habits The first synthesis involves the concepts of *repetition, opposition,* and *adaptation,* Gabriel Tarde (1843-1904), whose work Deleuze praises highly as "one of the last great philosophies of nature, in the tradition of Leibniz" (Deleuze 1994, 313). Tarde impacted the budding fields of sociology, social psychology, and criminology, especially with his concepts of *imitation* and *innovation*, but repetition, opposition, and adaptation play prominent roles in *Social Laws*: *An Outline of Sociology* (1898), as the fundamental categories governing all phenomena. It is through *opposition* that distributes individual differences throughout *repetition*. *Difference and Repetition* is influenced by Tarde's affirmation of difference "which opposes nothinhg and which serves no purpose" (Tarde 1897, 445). Deleuze writes that "*what Tarde inaugurates a microsociology*" (Deleuze 1994, 314). Tarde's microsociological method of thought enables expression of how on deeper strata of biological, psychological, and sociological strata repetition innovates through individual differences, through small variations, and ultimately the infinite repetition of the "differently different" (Tarde 1893), of *continuous variation*. Deleuze's work expresses and exhibits the philosophical thought that "repetition is, for itself, difference in itself" (Deleuze 1994, 91).

5.4 Rhythm-Repetition and Cadence-Repetition

> *Repetition is everywhere, as much in what is actualized as in its actualization. … In every case, repetition is the power of difference and differenciation: because it condenses the singularities, or because it accelerates or decelerates time, or because it alters spaces. Repetition is never explained by the form of identity in the concept, nor by the similar in representation. No doubt conceptual blockage gives rise to bare repetition that we can effectively represent as the repetition of the same*
>
> Gilles Deleuze, *Difference and Repetition* (1994, 220)

Deleuze's philosophy of time in *Difference and Repetition* develops three passive and active temporal syntheses, which conceptualize rhythms of all kinds. The concept of rhythm in Deleuze (1994, 2004, 2013) and in his work with Guattari (1972, 1980, 1991) prepares for an explication of the role of the passive and active temporal syntheses, as it is situated within the larger philosophy of difference and becoming created in the works under consideration. The role of the temporal syntheses must be conceptualized under the rubric of repetition and difference, but also under the rubric of time as the pure and empty form of change, a rubric resultant of the Copernican turn in temporality. The purpose of the chapter is to assemble the cyclic repetitions of biological rhythms with the deeper rhythms of evolutionary change. The temporal syntheses central to Deleuze's philosophy are rich resources to mine for the sake of embracing this uniquely philosophical task. The philosophical conceptualization of time relates to physical, psychological, biological, and otherwise empirically tractable temporal modes in *transversal* ways, which means in ways that cut across these modes with *consistency*. Time in this philosophical sense is not presumed in the dissertation to determine how these modes "hang together," but it does claim to determine how the problems of the EES hang together, or coexist in their different modes and tempos.

The concept of *rhythm* threads the needle and weaves its way through the modes of thought encountered during the course of the sections. Rhythm has played an important conceptual role in the earth, life, and social sciences, and has been developed in creative and useful ways through evolutionary and philosophical thought (Leroi-Gourhan 1993, Simondon 2017, Deleuze 1994). Chapter Two alluded to paleontologist Andre Leroi-Gourhan's theory of the exteriorization of time—from the third part of his masterpiece, *Gesture and Speech* (1964)— for the sake of corroborating the unconscious depth of time's subordination of time to movement. Time is exteriorized through technologies that foster sociocultural norms of timekeeping based on *idealizations* (Godfrey-Smith 2009, 2014) about the nature of time, presuming "ideally equivalent intervals," and the simultaneity of events, which are conducive to *operational sequence* control. The "unconscious opportunism," the automatic penchant, to assume the nature of time reducible to these norms has biased the sciences, and "human time" more generally, to construe time invariant, merely linear, and metrically captured by technologies of measurement, when "measurement of lived time refers to phenomena unrelated to measurement as such" (Leroi-Gourhan 1993, 315-318). Leroi-Gourhan's work is a powerful impact on the lineage of Deleuze's philosophical thought, and specifically his concept of rhythm, the depth of which is expressed in a philosophically rich section of *Gesture and Speech*: "Rhythms are the creators of space and time, at least for the individual. Space and time do not enter lived experience until they are materialized within a rhythmic frame" (Leroi-Gourhan 1993, 309).

The aesthetics of rhythm are fundamental to Leroi-Gourhan's theory of human evolution. As explored in part three of *Gesture and Speech* (1964), aesthetics is as evolutionarily powerful in the hominin lineage as technics and language. Leroi-Gourhan's novel approach to evolutionary problems is stylistically shaped by aesthetic sensations and their subterranean logic, but art's creative dynamism factors into the deepest fold of his theoretical experimentation. Aesthetics are evolutionary forces, especially propelling the course of human evolution. Its evolutionary dynamism is so deep and ubiquitous in the human lineage that it has been overlooked—too near to notice. It is not surprising, after all, that humankind across the earth immediately associate rhythm with music, dance, and other aesthetic activities. Evolutionary biologist and influential theorist of cultural evolution writes that “even before birth fetuses begin acquiring elements of the sounds and rhythms of the languages spoken by their mothers” (Henrich 2015, 233). Leroi-Gourhan enfolds the active and passive temporal syntheses of technology, language, and rhythm into one spatiotemporal dynamism: “tools, language, and rhythmic creation are three contiguous aspects of one and the same process” (Leroi-Gourhan 1993, 366).

Leroi-Gourhan’s influential theory of technical evolution through the keystone concept of *operational sequence* is a formative influence on the rhythmic syntheses of time. Every biological rhythm is differentially connected with other rhythms. The persuasive pull of his case consists in the transition from technical to musical rhythms: “The distance between musical rhythm, which is wholly a matter of time and measure, and the rhythm of the hammer or hoe, which is a matter of immediate or deferred procreation of forms, is considerable” (Ibid. 310). While both processes involve repetitious patterns (or operating sequences), musical ones do not aim to produce an artifact or consequence of direct utility, but rather to create its duration as an end in itself. Technical rhythmicity is a direct attempt to reshape the material world for survival purposes. Musical rhythmicity is an *affective* reshaping of individual and group compositions. Leroi-Gourhan travels from chaos to cosmic and terrestrial rhythmicity, on through various physiological, phenotypical, and technical rhythms to *musical* rhythmicity—concomitant with spontaneous dance. All the while he makes a compelling case for *Australopithecine* aesthetics and especially percussive rhythm and dance of a “figurative” style (Ibid.). The distinction between cadence-repetition and rhythm-repetition reprises this argument.

Deleuze’s philosophy of becoming is specially equipped for conceptualizing the modalities of temporality without the expression of these modalities falling into performative contradiction.

Temporality is a multiplicity. The modalities of temporality are bifurcating multiplicities—repetition itself is a manifold of pure and empty change, subjecting the self, subjecting the philosopher, to continuous variation. Therefore the concepts of *repetition*, *manifold* and *time* are manifolds of dimensions, degrees, and creases of differential connectivity, perpetually becoming—these two concepts, in other words, exemplify what they express. The syntheses of "Repetition for Itself" exemplify the irreducible and aleatory lives of their concepts.
Deleuze's concept of time thinks itself as a becoming, as a time (or repetition) of transformation. Deleuze's transcendental approach thinks the problem of difference, which converts effects traditionally attributed to identity, to difference, from substance to manifold.

Difference and Repetition is a work of philosophical experimentation aiming to transcendentally think problems of God, World, and Self through the optics of difference rather than identity. God is the primary identity (or substance) to which effects are traced.
Contemporary philosophy continues to illegitimately assume identity's priority over difference, though not necessarily in reference to God. Deleuze's philosophy converts God into a differential universe of pure modality and infinite variability. Pure differences are not mediated via identities, similarities, or oppositions. Difference relates differences through repetition. Variation operates at the heart of *Difference and Repetition* as the differential element constitutive of repetition, the internal insurance of repetition's productive capacity of differentiation in any repeated instant. Repetition as differentiation affirms the dissolution of every past identity and the differential becoming of these identities by the advent of preindividual singularities, novel differentiations. The infinite variation of the universe is not necessitated by predetermined plans perpetuating sameness, but by the repetition of pure differences. The three syntheses explicate Deleuze's novel concept of repetition, attempting to conceptualize the sufficient reason, the *ground*, of repetition itself. The pure past grounds the *foundation*, which is the living present, while both are *unfounded*

by the future advent of novelty. The irreducible modalities of metamorphosis are asymmetrical temporal syntheses coexistent upon a plane of continuous variation. Past, present, and future are not separate parts of time but rather operative dimensions of one another, alternately acting on one another across series of events (or becomings). When the present contracts the past, the past and future are the dimensions of its becomings (first synthesis); when the pure past as an open whole creates a coexistence between the past and the present, the present and future are the dimensions of its becoming (second synthesis); and when the future produces the new the past and future dimensions of its becoming contingently actualize. Present, past, and future modalities do not have to venture outside themselves to interact with each other. The multiplicity of temporality is not a pre-existent event space but is the production and becoming of events (as what Bergson called an Open Whole).

Difference and Repetition conceptualizes time under the rubric of repetition, as nonmetric and non-chronological manifold of passive and active syntheses. Deleuze's syntheses of time are forms of repetition, and their roles in Deleuze's philosophy of time provide a defense of *repetition for itself*. The manifold nature of rhythm enables a pivotal partition of repetition: "the study of rhythm allows us immediately to distinguish two kinds of repetition," cadence-repetition and rhythm-repetition, "the first being only the outward appearance or the abstract effect of the second" (Deleuze 1994, 21). Biological and evolutionary rhythms imply forms of *repetition*, a key concept in the work of Deleuze (Deleuze 1994, 2003). Cadence-repetition is a "regular division of time, an isochronic recurrence of identical elements," whereas rhythm-repetition is a "tonic assent, commanded by intensities" (Ibid.). Time as the pure and empty form of change, as continuous variation, is for Deleuze the transcendental condition of the three forms of repetition, which Deleuze explicates in terms of three *passive* syntheses of time (Deleuze 1994, 2013), a philosophical experiment with Kant's active synthetic approach, which follows through with the revolution spurred by Newton and Kant. The difference in kind between time and the temporal multiplicity of various localities (chemical, biological, cultural, etc.) is a problematic intrinsic to the construction of stratigraphic time. The continuous variability of time as the pure form of change enables the stratigraphic passive and active temporal syntheses (or modes of repetition) observable of earth. The temporal syntheses central to Deleuze's philosophy are rich resources to mine for the sake of embracing this uniquely philosophical task. Chapter 6 thinks through Deleuze's transformation of Kantian synthesis, enabling the conceptualization of time's modes and tempos in distinctive relation to time itself. Time itself is conceptualized as the pure and empty form of change, as *continuous variability*, whose modes and tempos are synthetically actualized by *cadence-repetition* and *rhythm-repetition* (Deleuze 1994, 21). The active and metrically equivalent periods of time characterizing cadence-rhythms are conditioned by the far more pervasive passive and unequal punctuations of time characterizing rhythm-repetitions.

Differential rhythms are spatiotemporal dynamisms, and "the dynamisms are no less temporal than spatial. They constitute a time of actualization or differenciation no less than they outline spaces of actualization" (Ibid., 217). The differential biological rhythms of evolutionary change are stratigraphically superimposed. "… there is a superimposition of disparate rhythms, an articulation from within of an interrhythmicity, with no imposition of meter or cadence. Consolidation is not content to be after; it is creative. The fact is that the beginning always beings in between, intermezzo. Consistency is the same as consolidation, it is the act that produces consolidated aggregates of succession as well as of coexistence, by means of the three factors just mentioned: intercalated elements, intervals, and articulations of superposition" (Deleuze and Guattari 1987, 328-9). "There is indeed such a thing as measured, cadenced rhythm, relating to the coursing of a river between its banks or to the form of a striated space; but there is also a rhythm without measure, which relates to the upswell of a flow, in other words, to the manner in which a fluid occupies a smooth space" (Ibid., 364). "It is well known that rhythm is not meter or cadence, even irregular meter or cadence: there is nothing less rhythmic than a military march. … Meter, whether regular or not, assumes a coded form whose unit of measure may vary, but in noncommunicating milieu, whereas rhythm is the Unequal or the Incommensurable that is always undergoing transcoding. Meter is dogmatic, but rhythm is critical; it ties together critical moments, or ties itself together in passing from one milieu to another. It does not operate in a homogenous space-time, but by heterogenous blocks. It changes direction" (Deleuze and Guattari 1987, 313).

The stratigraphic temporality of adaptation compels a conceptual heterogenesis of adaptation. Deleuze's first temporal synthesis, or mode of repetition, which features the core conceptual component of *habit*. The passive syntheses of habits The first synthesis involves the concepts of *repetition, opposition,* and *adaptation,* Gabriel Tarde (1843-1904), whose work Deleuze praises highly as "one of the last great philosophies of nature, in the tradition of Leibniz" (Deleuze 1994, 313). Tarde impacted the budding fields of sociology, social psychology, and criminology, especially with his concepts of *imitation* and *innovation*, but repetition, opposition, and adaptation play prominent roles in *Social Laws*: *An Outline of Sociology* (1898), as the fundamental categories governing all phenomena. It is through *opposition* that distributes individual differences throughout *repetition*. *Difference and Repetition* is influenced by Tarde's affirmation of difference "which opposes nothinhg and which serves no purpose" (Tarde 1897, 445). Deleuze writes that "*what Tarde inaugurates a microsociology*" (Deleuze 1994, 314). Tarde's microsociological method of thought enables expression of how on deeper strata of biological, psychological, and sociological strata repetition innovates through individual differences, through small variations, and ultimately the infinite repetition of the "differently different" (Tarde 1893), of *continuous variation*. Deleuze's work expresses and exhibits the philosophical thought that "repetition is, for itself, difference in itself" (Deleuze 1994, 91).

5.5 Passive and Active Temporal Syntheses (or Modes of Repetition)

First Synthesis: Habit, Law, and the Living Present. Before explicating the three passive syntheses of time, the syntheses must be considered in terms of their roles under the rubric of a new conception of repetition, and then explain why temporal processes must necessarily be conceptualized as syntheses. *Difference and Repetition* conceptualizes time under the rubric of repetition, as non-metric and non-chronological manifold of passive and active syntheses. Deleuze's syntheses of time are forms of repetition, and their transcendental role in Deleuze's philosophy of time provide a defense of "Repetition for Itself"—the title of the second chapter of the work—whereby the paradox of the sameness and difference of any given repetition is explicated in terms of time, serving as a formal case of the paradox. The three types of passive syntheses are as follows: (1) habit, which 'prioritizes' the present, what Deleuze calls the *living present*, as contraction of the past; (2) memory, which prioritizes the past as the pure fullness of any given present, in a bifurcating relation of coexistence with the present, enabling it to pass (or flow); and (3) the new, which prioritizes the future, and refers to the productive processes of temporality. The irreducible modalities of metamorphosis are asymmetrical temporal syntheses coexistent upon a plane of continuous variation. Past, present, and future are not separate parts of time but rather operative dimensions of one another, alternately acting on one another across series of events (or becomings). When the present contracts the past, the past and future are the dimensions of its becomings (first synthesis); when the pure past as an open whole creates a coexistence between the past and the present, the present and future are the dimensions of its becoming (second synthesis); and when the future produces the new the past and future dimensions of its becoming contingently actualize. Present, past, and future modalities do not have to venture outside themselves to interact with each other. The multiplicity of temporality is not a pre-existent event space but is the production and becoming of events (third synthesis).

Habit is conceptualized as contraction (or condensation) of the past by the living present, which changes the components of its future assemblage: "…there is no present which is not haunted by a past and a future, by a past which is not reducible to a former present, by a future which does not consist of a present to come. Simple succession affects the presents which pass, but each present coexists with a past and a future without which it would not itself pass on" (Deleuze 2013, 37). Living processes are presently occurring contractions synthesized by differential singularities. A body is not only different in its temporal rhythms in relation to other bodies, its rhythms first and foremost differ from itself (Deleuze 1968/1994, 31-33). When passive syntheses (of the present) repeat with regularity, they become somewhat sedimented— habits are formed. Habits are plastic patterns of becoming with variable durations, some briefly actualizing and fading in a life, others passing between societies in a generation, and still others becoming inherited across generations. The intergenerational inheritance of a habit (or network of habits) can be acquired via cultural transmission, and if cultural norms and institutions establish high bandwidth and fidelity, they shape genetic inheritance to accommodate them. An additional argument is necessary to evaluate the adaptability of a habit. Virtualities are actualized via the rhythms of individuation—via the spatiotemporal dynamisms of durational personhood. Phylogenetic rhythms are actualized by ontogenetic rhythms of individuation. The rhythms of a life's condensations of the present characterize the differential capacity of its affective, which perpetually modify a life's habits. The rhythmic dynamics of elephants, hearts, sugar cubes, proteins, strands of genetic heritability, cultural institutions, even storms and mountains, contract presents according to different habits and plastic capacities for becoming. A life is a multiplicity of rhythmic forces, some in fusion, others in tension, perhaps even in combat. Habits passively synthesize particular lifeways in asymmetrical relation to the past, and this asymmetrical relation refuses the reduction of becomings to historical succession: "contraction is essentially asymmetrical: it goes from the past to the future in the present, thus from the particular to the general, thereby imparting direction to the arrow of time" (Ibid. 71-73). It is not that the sand of time slips rapidly through our historically grasping hands, but that the sand of time becomes varied in its very passage, and that the sand in hand at any given instant of contraction is an irreversible event of singular change of the past. Though the asymmetrical relations between times foreclose sequences of isomorphism, they are nevertheless inclusive of one another in a differential network of becoming. Any present previously in existence changes at once when engaged, entering into events of new becoming. So not only are the productive asymmetrical processes of temporal manifold irreducible to any identity or predetermined series, they are also irreversible. The operation of habit therefore renders the return to and historical reconstruction of past instants only a very limited actualization of the past—just as a relation to past instants is determined the living present productive of that determinate relation (of succession) changes the instants contracted.

Second Synthesis: Memory, History, and the Past. Fossils, tools, artworks, and extracted genetic information may produce an inferential set of functional conditions for the evolution of the hominin lineage, but the dynamism of stratigraphic temporality resists representation. The spatial and temporal relations of these relics purport to represent a symmetrical set of functions isomorphic to morphological phases of human evolution, but Deleuze's concept of *asymmetry* turns these inferred symmetrical relations into aleatory syntheses asymmetrically and passively produced by sets of pre-individual singularities (not by traceable causal chains or homeostatic clusters of regularities). Though the asymmetrical relations between times foreclose sequences of isomorphism, they are nevertheless inclusive of one another in a differential network of becoming. There is not a past to reconstruct with the technologies and methods of evolutionary scientists, for any present previously in existence changed at once, entering into events of new becoming. So not only are the productive asymmetrical processes of temporal multiplicity irreducible, they are also irreversible. The originary operation of habit therefore renders the scientific return to and historical rationalization of past instants only a very limited actualization of the past via function and reference—just as a historical relation is determined the living present producing that determinate relation (of succession) is changing the instants contracted. "*All history does is to translate a coexistence of becomings into a succession*" (Deleuze and Guattari 1987, 430). A succession of instants organized into an evolutionary history does not constitute time, nor can it simply grant time the status of independent variable, for the first temporal synthesis contracts the past as a perpetual "change-agent," as an originary operation that acts on the repetition of instants such that becoming between instants always exceeds and changes the sequential processes of history. "This synthesis," writes Deleuze, "contracts the successive independent instants into one another, thereby constituting the lived, or living, present. It is in this present that time is deployed" (Deleuze 1968/1994, 70). Thinking in between multiplicities as sets of lines instead of terms, points, and elements. Lines pass between points, and so sets of lines elude the unities of temporal points, the "time stamps," assembled by history, archaeology, genetics, cultural anthropology—any discipline that turns lines of temporal multiplicities, which are "true *becomings*" (Deleuze 1987, 124), into chronologically, spatially, and causally ordered sequences. Times are everywhere becoming and nowhere captured by history.

The pure past (or pure memory) *grounds* the passive syntheses of habits, which are the *foundations* of time (Deleuze 1968/1994, 80):

> **Habit is the foundation of time, the moving soil occupied by the passing present. The claim of the present is precisely that it passes. However, it is what causes the present to pass, that to which the present and habit belong, which must be considered the ground of time. It is memory that grounds time. We have seen how memory, as a derived active synthesis, depended upon habit: in effect, everything depends upon a foundation. But this does not tell us what constitutes memory. At the moment when it grounds itself upon habit, memory must be grounded by another passive synthesis distinct from that of habit.**

Deleuze's philosophy resists any subordination of differences to identities, such as founding essences or causal mechanisms. It rather grounds habit in the open whole of the pure past. As an open whole, the passive synthesis of the pure past perpetually produces potentials for the advent of novel futures, and through such productive processes, opens up new pasts in turn. The pure past as a virtual accompaniment of presents is deduced along a series of paradoxes (contemporaneity, coexistence, pre-existence, and the Bergsonian metaphor of the cone). Amid the paradox of the contemporaneousness of the past and present in the first synthesis and the simultaneous paradox of the pure past pre-existing the passing present in the second synthesis, the concept of the field of coexistence becomes important. The pure past coexists with the present as a virtual past, which implies a future of the past via the becoming of the present. This thesis grates against commonsense, which presupposes that the past is immutably behind us, having utterly ceased to be (Deleuze 1968/1994, 55).

The pure past is not a psychological register, but rather a pre-individual multiplicity of virtuality. "The past and the present," he continues, "do not denote two successive moments, but two elements which coexist: One is the present, which does not cease to pass, and the other is the past, which does not cease to be but through which all presents pass. It is in this sense that there is a pure past. … The past does not follow the present, but on the contrary, is presupposed by it as the pure condition without which it would not pass. In other words, each present goes back to itself as past" (Deleuze 1968/1994, 59). The past is contemporaneous with the present in its entirety, as a multi-leveled and moving whole open to infinite variation. These levels are the intervals of coexistence across which differential processes of becoming individuate virtualities as actualities. The virtual levels of the past are dynamically concatenated, more or less expanded or contracted depending on the conditions of its individuation. The levels of coexistence are not constituted by actual repetitions of physicality and mentality upon a single plane, but rather through infinitely variable expansions and contractions upon a multiplicity of virtual planes. Each level thus differentially contains the whole of the past. If the past is not itself at the same time as the present passes then it will never enter becomings. The field of social coexistence is not an empirical collection of concrete social formations. It is the "plane of immanence," the non-chronological transcendental field wherein all social powers coexist in virtual interactions of becoming, a plane of coexisting though diverging temporalities.

Third Synthesis: Novelty, Contingency, and the Future. Experiences and measurements of time are commonly represented by active syntheses, as chronologically organized sequences. The passive syntheses provide the conditions of the experience and measurement of time. The synthetic processes of the living present connect instants while the conjunctive synthesis of memory, of the pure past, grounds contractions of living presents across levels of coexisting times. The third synthesis concerns the advent of the production of the new. The radical novelty of production relates to the living present and pure past through disjunctive synthetic processes, splitting the virtual past and the actual present, consistently opening the whole of the pure past to enable the living present to pass into novel production. Deleuze's *Cinema 2: The Time-Image* makes speedy yet impactful claims about the non-chronological nature of time. After Kant's inversion of priority in the relation between time and movement, the tendency to chronologically order time is upset by contingently aberrant movements, movements of the ordinary, the advent of which are non-chronological. The problems of coexistence and novelty demand concepts of non-chronological temporality. Deleuze conceptualizes these non-chronological modes of time in a highly unique fashion, but such is called for in response to such a challenging problem.

Even if Deleuze's conceptualization is too idiosyncratic and empirically intractable, it is a task infrequently encountered in the philosophy of time, and so Deleuze's concepts open a provisional (and compelling, at least according to the present effort) juncture needed for a philosopher or scientist to begin. Non-chronological time is "the perpetual foundation of time" (Deleuze 2013, 81). The virtual manifold actualizes the temporal syntheses through non-metric and non-chronological processes. For individuals in the Kantian framework time is the very form of interiority, of inner sense, whereas for Deleuze individuals are interior to time, and "…the only subjectivity is time, non-chronological time grasped in its foundation, and it is we who are internal to time, not the other way round" (Ibid, 85). Thought or the brain, according to Deleuze, is "the set of non-localizable relations" between what he calls "sheets" of affecting and being affected, of active and passive syntheses (Ibid, 125). These relations are non-localizable in that they transverse domains or strata of synthesized temporality via non-chronological processes of differenciation between virtuality and actuality. The multiplicity of non-chronological temporal processes neither emerge from nor actualize between actual movements or events, but are rather individuations of a virtual field of coexistence, of infinitely variable singularities. Time is nonchronological in that the past is not composed of linear sequences between befores and afters. Chronometric measurements of time depend on a temporal manifold of pre-individual and nonlinear singularities. The non-chronological nature of purely virtual time consists in the coexistence of the past with the present it was previously, and "the past is preserved in itself, as past in general (non-chronological); at each moment time splits itself into present and past, present that passes and past which is preserved" (Ibid, 85). The pure past and the passing present split in homogeneous directions, and are thus resistant to chronological sequencing. The paradoxical characteristics of non-chronological time are "the pre-existence of a past in general; the coexistence of all the sheets of the past; and the existence of a most contracted degree" (Ibid.).

The new is conditioned in a subtle sense. The conditions cannot be causes (or even dynamically clustering causes) producing effects from pre-existing forms or elements (as according to the hylomorphic model of creation), for then the new would be (to some degree) determined in an only partially novel fashion. For a determination to be new the conditions must be differential—they must constantly bifurcate upon actualization, producing novel forces of further fragmentation. As a pure form of time, the passive synthesis of futurity "unfounds" time and bifurcates actualities. In the conclusion to *Difference and Repetition* 272-277), arguably Deleuze's magnum opus, the problem consistently (if not always explicitly) driving the work as a whole is sufficient reason, which entails a "twist," a "bend," a "virtual curve" relating what sufficient reason "grounds to that which is truly groundless" (154, 272). Deleuze uses the familiar however nebulous concepts of *ground* and *foundation* in novel fashions in connection with *ungrounding* or *groundlessness*—an innovative concept of *continuous variation* key to Deleuze's philosophy of time. If "grounding is the operation of sufficient reason" (272) it is at once "strangely bent: on the one hand, it leans towards what it grounds, towards the forms of representation; on the other hand, it turns and plunges into a groundlessness beyond the ground which resists all forms and cannot be represented" (274-275). Virtuality is the sufficient reason for the advent of the new (Smith 2012, 240-241, Roffe 2019, 52). The sufficient reason is multiple, virtual multiplicity, "a system of multiple, non-localizable connections between differential elements…incarnated in real and actual terms" (Deleuze 2013, 183). Stratigraphic time conceptualizes the virtual multiplicity of evolution and its modes and tempos of "creative actualization."

5.6 Concluding Thoughts

The EES is a compelling if conceptually nascent rethinking of evolutionary theory bursting forth and progressively blooming since the turn of the century (Gould 2002, Pigliucci 2007, Laland et al. 2015, Müller 2017). The framework of the EES is naturally in nascent stages of construction, still in a conceptual incubator, as it strives to make a sufficient case for the pertinence of processes, scales, and patterns previously neglected by the MS. The introduction provided ground-level characterizations of the Modern and Extended evolutionary syntheses. The MS and the EES are mined the sake of provisionally capturing the temporal presuppositions endemic to the respective syntheses' tacit and explicit theoretical lineaments (in Chapter 1). This provisional approach had the perk of illuminating how the problem of time in geology, paleontology, evolutionary biology, and other related fields has changed over the roughly two centuries spanning the geological advent of the concept of deep time and contemporary evolutionary theory. The explication of the problem of time in the history of philosophy and physics assists the philosopher in determining the problem of time in geology, evolutionary biology, paleontology, etc., by thinking *through time's various subordinations to movement*, instances of what Poincare called an "unconscious opportunism" predominantly operative the history of science. The analysis and evaluation of this "unconscious opportunism" is guided by Deleuze's philosophy of time in Chapter 3. The dissertation offers a new concept of evolutionary time aiming to succeed where Gould fell short by instilling the currently most promising evolutionary synthesis with a philosophical plane of consistency through which scientific and theoretical work salient to the EES may resonate and interfere.

The dissertation aimed to conceptualize the lineaments of evolutionary process developed in the EES in the light of a cogent and compelling concept of evolutionary time. It argued that philosophers of nature should (1) disabuse themselves, philosophers of sciences, and scientists of the unconscious opportunism of chronometric time and (2) construct a new and pragmatically compelling conceptual assemblage apt to encounter the problem of evolutionary time. Philosophers and scientists concerned with evolution are pressed to newly conceptualize the nature of history, the structural segments or units of temporal measurement, the assumption of gradual change, the determination of temporal scales (evolutionary, developmental, geological, etc.), and ultimately the causal dynamics operative in evolutionary modes and tempos. The nonchronological virtuality of time as continuous variation problematizes the chronometric subordination of evolutionary time to evolutionary causal movement, which problematizes its tacit assumptions and explicit inferences concerning evolutionary causality, which are incapable of accommodating the empirical motivators of "a new and expanded synthesis." The concept of stratigraphic time attempts to think evolutionary process as a rhythmic multiplicity of passive and active syntheses, which modify not time itself—infinite and continuous variation—but time's modes and tempos.

Compelled by converging research in the natural sciences suggesting the stratigraphic nature of time, I argued for a temporal approach to the venerable problem of *synthesis* in evolutionary theory, that *nothing in evolution makes sense except in the light of time*, such that the problem of evolutionary time plays a powerful role in making sense of the conceptual architecture of the EES. I created the philosophical concept of *stratigraphic time* to strengthen connections between the four problem agendas or "causal catchalls" structuring the new synthesis: (1) *developmental plasticity*, (2) *developmental bias*, (3) *inclusive inheritance*, and (4) *niche construction* (Laland 2015 et al.). The dissertation developed two critical arguments (Chapters 1-3) concerning the subordination of time to process, and two constructive arguments (Chapters 4 and 5) concerning the nature of evolutionary time, which together attest to the conceptual strength of a temporal approach to the multiplicity of evolutionary problems pursued by the EES, and especially the connections between them.

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