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ESSAY REVIEW

Evolutionary Theory Developing: The Problem(s) With *Darwin's Dangerous Idea*

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Daniel Dennett's book, *Darwin's Dangerous Idea*, is presented as an historical account and explication of evolutionary theory, and a demonstration of how Darwin's "dangerous idea" provides an explanation of the psychological or epistemic dimension of the world (or of mind in nature). Its real agenda is to present Dennett's own theory of the origin of "mind" in nature, a kind of computer age, neo-Pythagoreanism that seeks to legitimize the claims of artificial intelligence by locating the source of all agency, meaning, or "mind," in an otherwise "dead" world of physics in algorithms. This approach continues the dominant tradition in modern science of radically separating the psychological and physical into two incommensurable parts, and it is this, the paradigmatic dualism at its core, and the erroneous and outdated empirical assumptions on which it is based, that are the book's undoing. By correcting these assumptions, a principled basis is provided for grounding a commensurable theory that dissolves the anomalies inherent in such Cartesian accounts.

INTRODUCTION

Daniel Dennett's *Darwin's Dangerous Idea*[1] (1995b) purports to present an authoritative history and explication of evolutionary theory, to vindicate Darwinian theory

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[1]In this essay I cite both Dennett's book (1995b) and his own essay by the same name that summarizes the central ideas of the book (1995a).

by showing the failure of what are given as the "major challenges" to it, and to show how Darwin's "dangerous idea," an idea that like "universal acid," according to Dennett, cuts through everything extending "far beyond biology" to culture or the world of human ideas, to thus provide an explanation of the psychological, intentional, or epistemic dimension of the world—an explanation of the origin of "mind" or "consciousness" in nature (p. 63). This, in fact, is the real agenda of the book, although it is to establish Dennett's own theory, not Darwin's, of the origin of "mind" in nature (and already set forth in his 1991 work *Consciousness Explained*), an account that attempts to legitimize the claims of "strong" artificial intelligence (AI), the mind-as-computer paradigm in cognitive science, by giving it an evolutionary context. Dennett's theory (call it "selfish algorithm theory"), a kind of contemporary, computer-age, neo-Pythagoreanism, is an extreme version of Dawkins' already extreme idealist reductionism ("selfish gene theory"; Dawkins, 1976/1989). The book is flawed by a particularly large number of logical and factual errors (see also Orr, 1996[2]), but all of these are minor compared to the fatal problems at its conceptual core. Because these problems are generic, and in their genericity, still widespread, a discussion of the book is useful as a means toward the end of both bringing them out, and showing why, in addition, they are essentially outdated artifacts or consequences that follow from a set of outdated premises. This article will no doubt contain too much discussion of some issues for some readers, and too little discussion of other issues for other readers, but I believe, in any case, that it contains at least sufficient discussion of the requisite issues to make the necessary points.

Old Dualist Deductions in New Packaging

Throughout *Darwin's Dangerous Idea,* Dennett uses the metaphor of "skyhooks" versus "cranes" to distinguish between miraculous ad hoc accounts of natural processes and legitimate scientific ones. The term "skyhook," which maintains its popular connotation here, is an excellent term in this context, but the term "crane" is not. Cranes, like computers, are externally designed machines or artifacts, and living things are not. This is not the only example of this kind in *Darwin's Dangerous Idea.* Dennett's choice of terms throughout the book works to blur the distinction between artifactual and self-organizing or autocatakinetic systems (discussed later), a requisite move if his theory is to be vindicated, but one that points to the fundamental category error at its core. The idea of skyhooks presents a different problem for Dennett. Historically, the invocation of skyhooks, the invocation of ad hoc extra-physical ordering agents, "mind-stuff," or "makers conjured out of thin air" (Swenson, 1990b, p. 35), is the hallmark of a dualist lineage that can be traced

[2]Orr has written a review from within the Darwinian paradigm that was brought to my attention by an anonymous reviewer after the present article had been written. This may be of interest to some readers.

from the Pythagoreans, through Anaxagoras, Democritus, and Plato, to mention a few of the most prominent names, and built into the foundations of modern science in the 17th Century with the bifurcated metaphysics of Descartes. The problem is that despite Dennett's loud protestations against skyhooks and various actual or alleged dualists, his own theory, by which he brings agency, and meaning or "mind" into an otherwise meaningless "dead" world of physics, is paradigmatic dualism.

Following Boltzmann's hypothesis of the second law of thermodynamics (the entropy law), Dennett's theory rests on the assumption that according to universal law, the physical world is expected to become increasingly more disordered (call this "the river that flows downhill"). This leads him to conclude that life, its evolution, the evolution of culture or of "mind" in nature, that, in contrast, is characterized by progressive ordering (call this "the river that flows uphill"[3]), thus defies the laws of physics (e.g., Dennett 1995b, p. 69). If this view is accepted, the deduction is simple: To get active ordering into the world requires the invocation of extra-physical or ideal ordering, and this, in fact, is the generic dualist or Cartesian deduction that, in Dennett's case, takes the form of "macros" or algorithms, an idea not surprisingly concordant with the view of strong AI that "mind" is constituted by algorithms. We have descended from, and all agency and meaning comes into the universe, according to Dennett (e.g., pp. 156, 203), with immaterial, potentially immortal, abstract bits of program or algorithms, like computer viruses.

Even putting the fatal logical problems of dualist schemes in general aside, Dennett's (1995b) algorithmic theory collapses on empirical grounds. Both the idea that algorithms are the ancestors of living things and the source of all agency in the world, and the idea of the two incommensurable rivers carried over from 19th century thermodynamics are empirically false. Rather than defying universal law, the river that flows uphill, the epistemic or psychological dimension of the world, as shown later, can now be understood as a direct manifestation of universal law. In contrast to a logically flawed and empirically untenable incommensurable or Cartesian theory such as Dennett's, this provides the basis for placing the epistemic dimension of the world in its universal context, and providing a commensurable or ecological theory of living things and their environments or of "mind" and nature.

Dennett's Darwinian Pedigree, "Whig" History, and the Evolution Revolution

If *Darwin's Dangerous Idea* were entitled *Selfish Algorithm Theory, The Algorithmic Theory of Mind, The Algorithmic Theory of Evolution, Dennett's Dangerous Idea*, or something similar, a demonstration of the empirical failure of its core principles would be the end of the story. After stating that "Darwin's theory has been abused

[3]This felicitous phrase is due to Calvin (1986).

and misrepresented by friend and foe alike," however, Dennett (1995b, p. 17) presents his book as a "true" and authoritative historical account and explication of an idea of Charles Darwin's, not his, and the "Darwinian Revolution" that is taken to have followed from it. What Dennett attempts to do is to exploit what Gould and Lewontin (1979) have called the "sainthood" or "divinity" of Darwin to legitimize his own theory. This is extremely misleading, however, because whatever may or may not be said about Darwin or his place in the history of evolutionary theory, he was certainly not a neo-Pythagorean reductionist like Dennett (or Dawkins). In addition, given the vast literature in the history and philosophy of science on the rise of evolutionary theory, Dennett's "Whiggish" account of the "Darwinian Revolution" is not only deeply misleading, but, like his thermodynamics, out of date. It is certainly not the "true" or accurate account of history that Dennett makes it out to be.

"Whig history" is the name given to an inaccurate or mythical view of history developed by systematically "distorting history ... to influence the general view of the past" (Bowler, 1988, p. 16) in a way that will support the position or social interests of those doing the constructing, and the Darwinian Revolution, perhaps the most widely studied scientific revolution in history, is commonly used by historians of science as an example. This is because, in Bowler's (1988, p. 16) words, although none of this is mentioned in Dennett's text, "this is exactly the pattern followed by the scientific community to create the conventional image of the Darwinian Revolution," an ideological myth that lent support to the rise of the Victorian capitalism and global industrialization. As a consequence, it has become common among historians and philosophers of science to refer to the popular conception of the Darwinian Revolution, the "great man" with the "great idea," as the "myth" of Darwinism (e.g., Bowler, 1988, 1989; Gilson, 1984; Løvtrup, 1987), and it is a rehash of this standard mythological history that Dennett presents without so much as a nod towards the widely known countervailing historical facts.

Paradigms are defined by their core assumptions, and thus to change from one set of core assumptions to another is, by definition, to change paradigms, or effect a scientific revolution. Whig histories, or historical creation myths, which in the context of modern science have typically taken the form of "great men stories," can be seen as part of what Kuhn (1962), Lakatos (1970), and others have recognized as the irrational or nonscientific component in scientific revolutions—part of the means by which the core assumptions of a "paradigm" in Kuhn's terms, or equivalently of a "research program" in Lakatos's are immunized or protected from challenge or falsification despite, or in the face of, countervailing or anomalous facts (call this "Kuhnian denial"). Kuhnian denial is isomorphic in all respects with denial as it is popularly understood at the individual level—the closer the challenge or set of countervailing facts to the core, and the more dysfunctional the paradigm, in other words, the more of a "degenerating research program," in Lakatos's (1970) terms, it is (see Appendix) the greater the measure of denial or irrationality.

Kuhnian denial is prominent in *Darwin's Dangerous Idea* in Dennett's Whiggish account of the Darwinian Revolution, in the way he attempts to link Darwin with selfish algorithm theory, and also his characterization of the state of contemporary Darwinism. Although one would never know it from reading Dennett's book, in which he writes that all the "major charges" against it have been contained (Dennett 1995b, pp. 313, 314), Darwinism today is in a fight for its theoretical life. In contrast to what are, in fact, the "big problems" that challenge Darwinian theory at its core, questions that, not coincidentally, bear a direct and deep connection to understanding the active, or epistemic, nature of the world, the "major charges" against Darwinian theory that Dennett invokes are strawpersons that typically play no role whatsoever in the current cutting-edge debates. Even Darwinians such as Depew and Weber (1995; Weber & Depew, 1996; Depew, in press), who have put forth their own attempt to expand Darwinism with the explicit hope of saving it from becoming a degenerating research program per Lakatos, express their lack of assuredness about whether Darwinism, in fact, can be saved. Other prominent former Darwinians, such as Salthe (1972), have already said goodbye to Darwinism in search of broader, more comprehensive theories (e.g., Salthe 1985, 1994; see also Swenson, 1991a, 1996, in press-c; Swenson & Turvey, 1991 for further discussion).

What follows is in four main sections. The first challenges Dennett's historical account, the second his view of life as an algorithmic process and as the source of all agency and meaning in the universe, the third his view that life is a process that works against or defies the laws of physics—the assertion of the two incommensurable rivers, and the fourth and final section, Dennett's claim that Darwinism, in any of its forms, is vindicated and secure.

"DARWIN'S (DENNETT'S) DANGEROUS IDEA(S)," THE "DARWINIAN REVOLUTION," AND THE SCOPE OF EVOLUTIONARY DISCOURSE

What Was Darwin's Idea?

Toward the end of building and then trading on Darwin's divinity to promote his own algorithmic theory of agency and mind in nature, Dennett repeatedly restates the great or "dangerous" idea of Darwin, the idea that is ostensibly the subject of the book, in nonequivalent terms that become progressively removed, as the book progresses, from anything Darwin ever said, or could have said. Upon being confronted with his ideas "the idea of evolution must have struck Darwin's contemporaries," Dennett (1995a) writes, as "utter nonsense, of course. Inconceivable" (p. 36). This implies that the idea of evolution itself was new with Darwin even to the wealthy, well-educated elite that made up his social circle. The impression that Darwin somehow invented or discovered the idea of evolution is the implicit idea conveyed by Dennett throughout the book and in standard Darwinian mythology (Løvtrup, 1987), although he (Dennett, 1995b) states elsewhere that "Darwin's great idea [was] not the idea of evolution, but the idea of evolution by natural selection," which he calls "the single best idea anyone has ever had" (p. 21). Then, following a discussion of the *if–then* logic of natural selection (see later), Dennett modifies this to say that what Darwin really discovered was an algorithm, and that "the idea that all the fruits of evolution can be explained as the product of an algorithmic process, is Darwin's dangerous idea" (p. 60).

Subsequently, in a different place, the idea that evolution by natural selection constitutes *an* algorithmic process is transformed into the idea that "incredible as it may seem the entire biosphere is the outcome of nothing but a cascade of algorithmic processes," and that "what Darwin discovered was not really one algorithm, but, rather, a large class of related algorithms" (Dennett, 1995b, p. 52) referring to "the phylum of evolutionary algorithms" (p. 53), and making it clear that he is now erroneously conflating the process of natural selection with that which it works upon. Continuing and adding to the confusion several pages later, Dennett then says that "Darwin's dangerous idea is that Design can emerge from mere Order via an algorithmic process that makes no use of pre-existing Mind" (p. 60), and finally, much later in the book he asserts that "heart and power of the Darwinian idea ... [is that a] robotic, mindless little scrap of molecular machinery (an algorithm or "macro") is the ultimate basis of all agency, and hence meaning, and hence consciousness, in the universe" (p. 203). From this he concludes that each of us and each of our grandmothers, and our grandmother's grandmother, etc. have all descended from robots (algorithms or macros; p. 206). Dangerous, great, or not, these are multiple claims and not a single idea. In addition, by and large, they were not Darwin's. Further, the ideas relating to algorithms, in fact, as is discussed later, conflict with ideas that were Darwin's.

The Idea of Evolution

Even though it is widely known that Darwin, as Huxley (1982) has written, "was certainly not the originator of the idea of evolution" (p. 3), the popular misconception to the contrary has been relentlessly promoted, either directly or indirectly, by texts such as Dennett's that make Darwin "the hero or founding father in the creation-myth of modern evolutionism" (Bowler, 1988, p. 16) and dramatically marginalize the contributions of others to make it seem as though the history of evolution and the history of Darwinism are one and the same. So successful has this enterprise been in making the history of evolutionary theory seem like a "one-man show" with the idea of evolution somehow "singlehandedly introduced and popularized" by Darwin (Bowler, 1988, p. 16), that today the terms *evolution* and *Darwinism* are typically taken to be synonymous (Løvtrup, 1987). Popular misconceptions aside, however, the widely held view that evolutionary theory effectively began (and in some sense ended) with Darwin, is a radical piece of revisionism (e.g., Bowler, 1988, 1989; Carneiro, 1972; Gilson, 1984). Contrary to the impression given by Dennett, the subject of evolution had been under widespread discussion for years before Darwin ever publicly expressed a word of it, and not just amongst the educated elite that comprised Darwin's social circle, but square in the face of the general public.

Robert Chambers is not even mentioned in Dennett's book, but in Britain, the idea of evolution (under the name *development*) was commodified and popularized, or "brought off the streets and into the home" (Secord, cited in Darlington, 1961, p. 8), by Chambers (1844/1969) a good 15 years before Darwin's *Origin*. Chamber's remarkable bestselling book, *Vestiges of the Natural History of Creation*, which "was immensely popular with the general public, and discussed at length in leading reviews" (Ruse, 1979, p. 94), went through seven editions in the first four months after it was published. Alfred Wallace, whose theory of natural selection was published simultaneously with Darwin's (see next section), was among those who acknowledged their deep intellectual debt to Chambers and his idea of evolution through natural law (Lovejoy, 1968, p. 362). Contrary to the impression created in *Darwin's Dangerous Idea*, where Dennett would have Chambers effectively erased from the pages of history, there is certainly no historical doubt that after Chamber's book the subject of evolution, in Ruse's (1979) words, "was no longer a private scientific question but a burning question that had been thrust upon the public eye" (p. 127).

With respect to recognizing the first person to popularize the idea of evolution using the word "evolution," it was Herbert Spencer, not Darwin, who did so (e.g., Bowler, 1989; Carneiro, 1972; Gilson, 1984). Introduced to the readers of *Darwin's Dangerous Idea* only near the end of the book as "one of Darwin's most enthusiastic supporters ... and an important clarifier of Darwin's ideas" (Dennett, 1995b, p. 393), Spencer is made to appear as a minor player who came along after Darwin and stood by on the sidelines cheering him on. In fact, it was Spencer (e.g., 1892/1852, 1852, 1857, 1862) who, well before Darwin, publicly took on the Creationists, or those who believed in the immutability or special creation of species, and then popularized and defined the word *evolution* in a prolific series of articles and best-selling books, each of which, like Chambers's *Vestiges*, went into multiple editions and translations. Although it is historically significant enough to merit pointing out the marginalization of the person who in fact did "the most to popularize the term 'evolution'" in the 19th century (Bowler, 1989, p. 9; Carneiro, 1972; Gilson, 1984), there is something far more substantive at stake, and this is the meaning of the term *evolution* itself and hence the scope of the whole evolutionary discourse. When Dennett and other Darwinian texts speak of evolution, and the discovery of natural selection as its explanation, they speak about evolution as defined by contemporary Darwinism today.

Contemporary Darwinism defines *evolution* as the consequence of natural selection (see next subsection), but this definition and the idea of natural selection itself were not widely accepted until after the synthesis of natural selection with Mendelian genetics, principally through the work of Fisher (1930/1958) in the 1930s (Bowler, 1989). Where Spencer is discussed, Darwinian texts often make the difference between a Spencerian theory and a Darwinian theory the assertion that Spencer was a Lamarckian who did not believe in natural selection, whereas Darwinian theories reject Lamarckism and see evolution as the result of natural selection (see later discussion on Darwin's actual views on Lamarckian inheritance). But one can readily go to Spencer's own words to see that this was not the case (e.g., Spencer, 1882). Spencer did not oppose natural selection—he thought it was an important evolutionary mechanism—but he did not think it was suitable as a first principle, or that it was an "explanation" for evolution, and this was principally because he did not view evolution in the very narrow sense of contemporary Darwinism.

Evolution for Spencer was a universal process of spontaneous ordering or self-organization with biological or organic evolution as a component process, or special case. "Evolution," wrote Spencer (1862), "is a transformation of the homogeneous into the heterogeneous, the indefinite into the definite, or the transformation of the incoherent into the coherent [the less ordered into the more ordered]," (p. 215) and this universal process that he called the "law of evolution" is the same "whether it be in the development of the Earth, in the development of life upon its surface, in the development of society ... from the earliest traceable cosmical changes down to the latest results of civilization" (p. 10). The study of evolution for Spencer was first and foremost a search for the nomological basis for this universal ordering, and clearly natural selection did not provide such a basis because it was simply a particular mechanism, the particular kind of dynamics, entailed in a particular kind of ordering (viz., "replicative ordering"; e.g., see Swenson, 1991b, 1992, 1996). Rather than explaining evolution, natural selection, on the Spencerian view, was a mechanism that was part of a process that awaited the right universal principles to explain it. Natural selection in different terms, rather than explaining evolution or biological ordering was something that waited to be explained by a general evolutionary theory that put it in the context of universal ordering.

Revolutions are defined by replacing one theoretical core with another, and what, in fact, happened with the Darwinian Revolution was the replacing of the theory of evolution as a universal ordering process with a theory about biological ordering following from natural selection. The revolution, or change in core assumptions, hinged entirely on the redefinition of the term evolution and with it the scope of the evolutionary discourse. Without this redefinition, the revisionist claim that with natural selection Darwin discovered the explanation for evolution could not possibly hold because natural selection does not explain evolution defined in the general or universal sense. Implicit in the Darwinian definition of the evolutionary discourse is a positive heuristic promoting the idea of the autonomy of biology from physics (Swenson & Turvey, 1991), and a negative heuristic against the search for universal principles. The idea that the history of evolutionary theory effectively began with the publishing of Darwin's *Origin* in 1859, at which point he convinced the world of the fact of evolution and at the same time explained it with the mechanism of natural selection, is a revisionist account by contemporary Darwinism that works to project its present narrow definition of evolution back into the 19th century. That neither evolution nor its explanation were conceived in this way at that time is well evidenced in the words of Darwin's most enthusiastic and influential 19th century supporter himself, Thomas Huxley. "Mr. Darwin," wrote Huxley (1878/1970) in his entry in the 1878 edition of the *Encyclopedia Britannica*, has made "numerous and important contributions to the problems of biological evolution ... [whereas] on the other hand, Mr. Spencer ... has dealt with the whole problem of evolution" (p. 212).

Finally, it should be noted briefly that many decades before the innovative and bestselling works of Chambers and Spencer, Erasmus Darwin, Charles Darwin's grandfather and a public figure in his own right, was steeped in the subject of evolution, promoting among other things the idea that "all living things were descended from a common ancestor" (Darlington, 1961, p. 26). In 18th century France, the influential naturalist Buffon wrote of the transformation of species, and he was followed by Lamarck with his widely read theory of evolution, while in Germany at the end of the 18th century, Schelling was writing about "the progressive development of nature as a 'dynamic evolution' [*dynamische Evolution*]" (Richards, 1992, p. 271), and Treviranus of the transformation of species, and there were many others.

The Fecundity Principle, the Idea of Natural Selection, and the Core of Darwinian Theory

Although there are many brands of Darwinism today, what unifies them all under the common name of *Darwinism* is the core concept of natural selection, the central principle according to which Darwinian theory is said to explain evolution (Depew & Weber, 1995). Attributing the idea of natural selection to Darwin, Dennett (1995b), as noted earlier, calls it "the single best idea anyone has ever had" (p. 21). Evolution, according to Darwinism, is seen as following from natural selection, and natural selection is entailed by what Popper (1985) has called a *situational logic*—namely, if certain conditions hold, then natural selection will necessarily follow. The most fundamental condition of this situational logic, often referred to as the *sine qua non* of the living, is the *fecundity principle*, a biological extremum principle that expresses the active striving of living things to fill out the economy of nature. The other conditions are heritable variation and the finite availability of resources (or the finite accessibility of space–time, a property, by definition, of space–time itself).

Because "every organic being," said Darwin (1859/1937), is "striving its utmost to increase, there is therefore the strongest possible power tending to make each site support as much life as possible" (p. 266). Paraphrasing Darwin, in Schweber's

(1985) words, this says that nature acts to "maximize the amount of life per unit area" (p. 38) given the constraints, and this is the essence of the fecundity principle. Thus, given a population of replicating or reproducing entities with heritable variation, "striving," in Darwin's (1859/1937) words, "to seize on every unoccupied or less well occupied space in the economy of nature," and given finite accessibility to resources, a "struggle for existence" *necessarily* follows, leading to the selection of the fittest variants, or to the "survival of the fittest" (p. 152). This is the idea of natural selection, and expresses the situational logic pointed out by Popper. If the idea of natural selection is the "best idea anyone ever had," then there are a number of people who should be given much more prominence in the history of science because the idea of natural selection was not new with, or exclusive to, Darwin.

Among the most clearly documented "discoverers" of the "best idea anyone ever had" were Matthew (1831/1971), who is marginalized as a historical curiosity in Dennett's book, and Wallace (1858), who is mentioned briefly. Others on the list who advanced the idea of natural selection prior to Darwin and receive no mention in *Darwin's Dangerous Idea* include Blyth (e.g., 1835), who wrote various articles on heredity, variation, and selection between 1835 and 1837, and the French botanist Naudin (1852), who made the comparison, as Darwin did later, to the "artificial selection" performed by human breeders. A number of scholars have questioned whether Darwin's discovery of natural selection was truly independent of these earlier sources or whether, in fact, he copied without citing, one or more of them (e.g., see Darlington, 1961; Eisley, 1979; Løvtrup, 1987).[4] In general, there is no conclusive evidence to ground the charges.

As soon as Darwin published the idea of natural selection, however, Matthew came forward publicly in print to claim priority to the idea. Darwin acknowledged Matthew's priority but said he had not been aware of Matthew's work when he arrived at the idea. The "adaptive disposition of life," Matthew (1831/1971) had written some three decades before the publication of the *Origin*, is the result of "the extreme fecundity of nature ... a prolific power (in many cases thousandfold) much beyond what it is necessary to fill up the vacancies ... As the field of existence is limited and pre-occupied, it is only the hardier, the more robust ... [who survive] the struggle ... [Those with] superior adaptation and power of occupancy ... come forward to maturity from the strict ordeal by which Nature tests their adaptation ... and fitness to continue their kind by reproduction" (p. 36). The issue of whether Darwin knew of Matthew's work before he started writing about the idea may be impossible to prove one way or the other, but what cannot be denied is that

[4]For example, Darlington (1961) has argued that Blyth's work appears to have been actually "copied by Darwin in his preliminary essays" (p. 61). Eisley (1979) has further suggested that Darwin cited Malthus as the source for the idea of the struggle for existence not simply because Malthus was a key figure in Whig politics, which counted Darwin among its supporters, but to cover his own debt to Blyth, who provided a more detailed account of natural selection and whom Darwin thus preferred to leave unmentioned (Løvtrup, 1987).

Matthew, among others, certainly had the "best idea anyone ever had," and he had it before Darwin.

Dennett mentions Alfred Wallace (1858), who is a bit harder to marginalize than Matthew, and some of the others who are not mentioned because he published the theory of natural selection at the same time and in the same place as Darwin. It was after Wallace's work came to light that Darwin's version was rushed to press through the efforts of his influential and wealthy circle of friends and published with Wallace's after a joint presentation to the Linnean Society. Dennett fails to mention some important points with respect to the differences between Darwin and Wallace. What is of particular interest here with respect to retrospectively making Darwin the one-man center of the evolution revolution, which by the now current Darwinian view as discussed earlier, is based on the idea of evolution by natural selection, is that although Wallace held strictly to the idea of natural selection as the core explanatory concept of adaptive evolution, Darwin increasingly separated himself from it.

In particular, as time went on Darwin turned increasingly away from natural selection and more toward Lamarck's idea of adaptation through the inheritance of acquired characters following the use and disuse of parts. "No one," thus, including Lamarck, wrote Darwin in a letter to *Nature* in 1880, "has given more examples of this than I have" (cited in Huxley, 1982, p. 6). In contemporary Darwinism, the theory of acquired characters is typically used to distinguish "Darwinism" (the "correct" theory) from "Lamarckism" (the "incorrect" theory), and at the same time discredit Lamarck who, as mentioned earlier, advanced his theory of adaptive evolution well before Darwin. The distinction is also used, as noted earlier, to discredit such other key players as Spencer for the same reason. But if rejecting Lamarkism is part of what makes a Darwinian a Darwinian, then between Darwin and Wallace it was Wallace who, in rejecting Lamarckian inheritance and remaining loyal to the idea of natural selection, was the true selectionist and thus the true "Darwinian" of the two. An argument could be developed on this basis that if contemporary evolutionary theory going under the name of "Darwinism" is about evolution by natural selection in contrast to evolution following from Lamarckian inheritance or a combination of the two, it might more appropriately have been named after Wallace. The same issue arises, as discussed briefly later, with respect to the work of Mendel.

On the question of the fecundity principle, which sits behind the process of natural selection, in effect "driving" the struggle for existence, or the striving to fill the economy of nature, as seen from Matthew's (1831/1971) own words, he clearly expressed it in the 1830s, and so did Chambers (1844/1969) in his bestselling *Vestiges* when he said that "the aim [of evolution] seems to be to diffuse existence as widely as possible, to fill up every vacant space with some sentient being" (p. 367). It is further worth noting that although Darwin, who cites Malthus for stimulating his thinking in this area, is often credited with taking Malthus's struggle for existence and generalizing it to the living world as a whole from human social systems, Malthus, in fact, had already argued that the struggle for existence was a general property of living things and then applied it specifically to human systems (Malthus, 1803/1992; see also Gilson, 1984). In addition, the struggle for existence had also been "clearly expressed" in the writing of Buffon, among others, the century before (Osborn, 1984, p. 136). The expression of the fecundity principle is much older than any of these 18th and 19th century sources, however.

It was Leibniz (e.g., 1697/1925; 1697/1969; Blumenfeld, 1981), some 200 years prior to any of those already mentioned, who advanced the idea that the actual world that exists is the consequence of the selection of the fittest from among a population of striving possibles in a struggle for existence. What motivates the struggle or the striving toward existence according to Leibniz is the fact that nature works inherently to maximize the magnitude of existence given the constraints—this is the fecundity principle writ large as a universal principle (that would make the biological or Darwinian extremum a special case). Leibniz's principle, in turn, can be seen as the development of the most fundamental metaphysical principle of the Platonic–Aristotelian tradition, what Lovejoy (1936/1978) has called the "principle of plenitude." In Plato's system, it is expressed as the "urge of the Demiurge" to produce order out of disorder, and in Aristotle as the motivation for the inherent striving of nature to turn potential into actual so as to fill out the sphere of being (see Swenson, in press-c, for further discussion). There is a direct line of descent from Leibniz through the evolutionism of Schelling and the search for symmetry or unifying principles to the discovery of the first law of thermodynamics by Robert Mayer, and the thermodynamic principles discussed below that provide the basis for understanding spontaneous ordering today. This lineage, which would certainly include Spencer, is distinct from the lineage stretching from Descartes through the teleo-mechanism of Kant (Lenoir, 1982), and through Darwin and Dawkins to Dennett.

The Idea(s) That Evolution Is an Algorithmic Process, or That We Are All Descended From Algorithms, or That All Agency and Meaning Come Into the Universe With Algorithms, Was/Were Not Darwin's Ideas

With Dennett's (1995b) idea that "your great-great-grandmother was … a macro" (p. 206) or that we all descended from macros, we see clearly the category error and illegitimate teleology on which his idealist reductionism is grounded. This and the claim that all agency comes into the world with little scraps of program or algorithms, as noted before, were not Darwin's ideas, and it is to put words in his mouth that he did not and, from everything we know, could not have uttered to say otherwise. The main source of these ideas is Dawkins, not Darwin, and Dennett and Dawkins, not surprisingly, enjoy a mutual admiration society, complimenting each other in their respective texts (Dennett complements Dawkins in *Darwin's Dangerous Idea*, and Dawkins Dennett in his 1995 book *River Out of Eden*, and on the cover of Dennett's book, which he calls "surpassingly brilliant").

Dawkins' idealist genetic reductionism, selfish-gene theory, or selfish replicator theory is almost ready-made for Dennett's attempt to justify the world-as-computer, or mind-as-computer view of AI. According to Dawkins "the genetic code is strictly digital," (1995, p. 12), and over evolutionary time, it is the basis for a digital river of selfish genes or "replicators" that "flows through time, not space ... a river of information ... of abstract instructions for building bodies" (p. 4). "Life," Dawkins says, "is just bytes and bytes and bytes of digital information," and "we—and that means all living things—are survival machines programmed to propagate" it (p. 19). Life, in different terms, is the production of selfish digital replicators toward the end of their own perpetuation and replication. "Computer programmers," says Dennett (1995b), call such "fragmented coded instructions ... 'macro[s],'" a term that he then adopts for Dawkins's genetic replicators—"bits of *program* or *algorithm* ... remarkably like ... computer viruses" (p.156).

Although the theoretical problems with these ideas will be discussed in the next section, the simple problem here with respect to Dennett's claim that these were Darwin's ideas is that there were no such "scraps" in Darwin's ontology at all. Setting aside the fact that he was neither an idealist nor a genetic reductionist, both facts sufficient in their own right to disqualify Darwin from being associated with Dennett's theory, Darwin's view of heredity (pangenesis) precluded such a digital view. In addition to the Lamarckian idea of the use and disuse of parts, Darwin's theory of pangenesis specifically invoked blending inheritance, not discretized units such as those that are at the core of selfish replicator theory with its concept of replicators as digitized pieces of program. It was Mendel's nonblending, discretized, or "digital" if you like, theory of inheritance, in contrast to Darwin's blending theory, that was rediscovered by biologists around the beginning of this century, and that provided the basis for reviving the idea of natural selection that was then in disrepute (e.g., Bowler, 1988).

In fact, the importance of Mendel's theory of inheritance versus Darwin's prompted Waddington (1975, p. 168) to propose that neo-Darwinism (contemporary "Darwinism") might more accurately be called "neo-Mendelism." The point is that even if Darwin were an idealist in the sense of Dawkins (which he was not), he never would have asserted anything like the idea that we have all descended from macros or that bits of program are the basis for all agency or intentionality for the simple reason that a digital, discretized, or nonblending, conception of heredity was not part of his theory. To suggest otherwise is extremely misleading. If this is the key idea of Dennett's book, then the title, if not *Dennett's Dangerous Idea*, might more accurately have been *Mendel's Dangerous Idea*, although even this would have been an extreme act of eisegesis because Mendel certainly was not an idealist reductionist like Dawkins or Dennett either. Neither Mendel nor Darwin ever suggested that living things were constructed as survival vehicles for the benefit of the hereditary "instructions" that were said to build and program them, and even more radically, were said, precisely like Cartesian "mind," to exist in time, not space.

Darwin Did Not Say "Give Me Mere Order And I Will Give You Design"

The "difference between Order and Design," according to Dennett (1995b), is that "Order is mere regularity, mere pattern: Design is Aristotle's *telos*, an exploitation of order for a purpose, such as the cleverly designed artifact" (p. 64).[5] As noted above, Dennett holds that according to the laws of physics (viz., the second law of thermodynamics), the world is moving from a more to less ordered state (p. 38). With respect to the evolution of life, Dennett says, "Darwin jumped into the middle with his proposed answer to the question of how Design could arise from mere Order. 'Give me Order, he says, and time, and I will give you Design'" (p. 65).

The problem with this assertion, like the ones in the preceding subsection, is that Darwin never said, or said anything like, "give me (mere) order and I will give you design." Understanding the problems with this claim points the way to recognizing some of the real, and insurmountable, limitations of Darwinian theory, and Dennett's illegitimate ad hoc smuggling by which he tries to get around them. First, even if Darwin had said something like "give me order," he would have been asking for plenty. Real-world living things presumably are part of or live in a physical world (although how the ideal entities at the core of the Dennett-Dawkins scheme connect with it, the old problem of Cartesian interactionism, is another problem), and Dennett has already said that the world according to the second law of thermodynamics constitutes a process of disordering. If this is true, then for Darwin to have asked offhandedly for order (really "spontaneous ordering") would have been to ask for something that, in effect, "defies" the laws of physics, as living things and evolution, in general, according to Dennett, do. If this were true, things would be bad enough, but this is not what Darwin said. What he did say, in fact, makes the problem much worse because what he asked for was much more.

What Darwin actually said (and Mathew, Naudin, Blythe, and so on before him), to paraphrase, and repeat in general terms, was: Give me the fecundity principle,

[5]Here, again, as with his use of the word *crane*, by both using the word *design*, a word appropriately used for artifacts, and using the case of conscious purpose as in a designed artifact to characterize Aristotle's *telos*, Dennett works to elide the distinction between artifactual and self-organizing or autocatakinetic systems. The choice of the word *design* speaks for itself, and with respect to Aristotle, as Grene (1966/1974, p. 228) has stressed, *telos* for him did not "mean primarily, much less exclusively" teleology, or end-directedness of the artifactual kind. Aristotle, as his criticism of the dualistic ad hoc ordering of Anaxagoras and others indicates, was in the lineage of those who saw the world as inherently active or self-organizing. It is the distinction between Plato's external and Aristotle's internal or immanent teleology that warrants emphasis (Hull, 1973; for discussion of Aristotelian causality and self-organizing systems, see, e.g., Swenson, 1990a, 1992, in press-a, in press-b, in press-c; Salthe, 1985, 1994).

heritable variation, and finite accessibility to resources, and natural selection will necessarily follow, leading to the selection of the fittest or best adapted variants. Or in other words, give me the finite limitations of space and time with respect to obtaining resources, a population of reproducing living things with hereditary variation "striving to seize on every unoccupied or less well occupied space in the economy of nature" (Darwin, 1859/1937, p. 152), and natural selection of the fittest or most well-adapted variants will follow.

In short, what is immediately clear is that Darwin did not say, give me *mere* order and I will give you the intentional ordering ("Design," in Dennett's terms, "purposeful" ordering, or the active, end-directed striving of living things), he assumed intentional ordering to begin with. Intentional ordering is an implicate of the fecundity principle and the fecundity principle is assumed in advance as a precondition from which *natural selection follows as a consequence*. This is a fundamental problem for Darwinian theory that, in its contemporary form, defines evolution as the *consequence of natural selection*. Because natural selection is a consequence of the intentional dynamics or intentional ordering of living things, the intentional ordering of living things is beyond the explanatory reach of Darwinian theory by definition. Darwinism in any of its forms, including Dennett's own extremized version, does not and cannot do what Dennett tries to make it do with these imaginary boasts of Darwin—an explanation of the intentional dynamics of living things, of the psychological or epistemic dimension of the world, or of "mind" in nature, is beyond the explanatory framework of Darwinian theory, and this, in effect, undermines Dennett's scheme from the beginning.

THE IDEA THAT AGENCY CAME INTO THE WORLD WITH BITS OF PROGRAM TURNS THE EVOLUTIONARY FACTS UPSIDE DOWN, INVOKES FALSE TELEOLOGY, AND BEGS THE BIG QUESTIONS

The idea that the physical world is inherently "dead," passive, or inactive, as noted earlier, was built into the foundations of the modern scientific world view with the dualistic metaphysics of Descartes, which paved the way for the rise of modern science in the 17th century, a process that, as a consequence, Merchant (1980) has felicitously called the "death of nature." On the Cartesian view, and for ideological reasons that have been well-discussed by historians of science (e.g., see Swenson, in press-b), the epistemic dimension, or active psychological part of the world was taken out of the physical world by dividing the world into two incommensurable parts, a move that left psychology and physics defined at their modern origins by their mutual exclusivity (the "first postulate of incommensurability"; Swenson, 1996). The "dead" world of physics ("matter"), defined exhaustively by its extension in space and time and governed by deterministic law, was contrasted with the active, striving, psychological part of the world ("mind") that was said to be immune from physical law and to exist without spatial dimensions (or, as with Dawkins's selfish replicators, in time not space).

As seen from the foregoing, an immediate implicate of the Cartesian mechanical world view was that spontaneous ordering, intentionality, and meaning were theoretically eliminated from the physical world by definition, and needed to be extraphysically imposed upon the supposed meaningless dead world of matter from the outside (by "mind"). Cartesian metaphysics came full-blown into modern biology with Kant who, recognizing that the active, end-directed striving, or intentional dynamics, of living things (not just human minds) could not be adequately accounted for as part of a dead mechanical world, called for the autonomy of biology from physics (Cassirer, 1940/1950), thus promoting a second major dualism, the dualism between biology and physics, or between living things and their environments (the "second postulate of incommensurability"; Swenson, 1996). Kant, following Blumenbach, was a teleo-mechanist or vitalist, invoking an active principle special to living things that, in effect, ordered and brought dead matter to life, imparting to it the active, end-directed striving, or agency, that characterizes living things (e.g., see Lenoir, 1982).

Contrary to the work of Darwin's predecessors such as Chambers and Spencer, who promoted universal theories of evolution, the idea of the autonomy of biology from physics, the second postulate of incommensurability, was carried into evolutionary theory with the ascendancy of Darwinian theory that made no use of physics or the nonliving part of the world at all in its theory. "Darwin," in Lewontin's (1992) words, "completely rejected [the] world view [held widely at his time] ... that what was outside and what were inside were part of the same whole system" (p. 108). "The fundamental dichotomy of evolutionary theory," as Levins and Lewontin (1985, p. 52) have put it, became "that of organism and environment," and in this way, through Kant and then Darwin, Cartesian metaphysics and its view of a "dead" mechanical world was effectively spread from the question of the nature of human minds and their relation to the world to life as a whole.

The second postulate of incommensurability gained strong apparent support with Boltzmann's hypothesis of the second law of thermodynamics as a law of disorder, and is still promoted actively by leading Darwinians today (e.g., Mayr's 1985 arguments for the autonomy of biology from physics). As noted, it is found prominently at work in *Darwin's Dangerous Idea* with Dennett's (1995b) assertions that living things are "organized in the service of the battle" (p. 38) against the second law of thermodynamics, or that living things "are things that defy" or constitute a "systematic reversal" of the second law of thermodynamics (p. 69). The view of an impoverished physical world that is thus built into the core of Dennett's scheme, as with all Cartesian schemes in general, becomes the justification for invoking extra-physical, immaterial, or ideal agents to animate the world and get it ordered. More specifically, it becomes the justification for adopting Dawkins's idealist reductionism to support Dennett's computational world view, where immaterial, active, striving, algorithms are used to bring all agency into the world and account for active epistemic ordering, or "mind" in nature.

As noted earlier, Dennett makes a number of separate and nonequivalent claims with respect to selfish algorithm theory that he erroneously blurs together or elides. The major example is the claim that natural selection, and hence evolution, is an algorithmic process, and that it is algorithms on which natural selection works—that living things have descended from algorithms, and hence constitute a branching phyla of algorithms. Although Dennett attempts to move seamlessly from one to the other, the two are not equivalent claims. In addition, they are both erroneous. The rest of this section is in four parts. The first will refute the claim that natural selection and hence evolution is an algorithmic process; the second the claim that our ancestors were algorithms; the third the claim that all agency in the universe is due to bits of program or algorithms; and the fourth, that evolution is for the good of "immortal" replicators.

Algorithmic Processes Have Been Produced By Evolution, But Evolution Is Not an Algorithmic Process

Computer programs are algorithms, and algorithms, as Dennett describes them, and as they are often described by others, are "recipes," or lists of step-by-step procedures of discrete rules or instructions for completing a task, solving some problem, or accomplishing some end. Like recipes and other rule-based procedures, algorithms, as ordinarily understood and defined, are artifactual productions of cultural systems (human social systems) and thus very lately evolved products of evolution. In his effort to computationalize evolution, Dennett would like to turn this empirical fact on its head and make evolution algorithmic process. What Darwin discovered with natural selection, Dennett says, was an algorithm, and his dangerous idea was that the products of evolution are thus explained as consequences of an algorithmic process. But natural selection is not an algorithmic process, and to claim that it is, as Dennett does, is to commit a category error.

Laws, rules, and the modeler's fallacy. As noted in the previous section, in 1985, Popper described natural selection as being entailed by a "situational logic," namely, *if* certain conditions are present *then* natural selection *necessarily* follows. Natural selection is a lawful process in this sense because it always happens if the conditions are met, and the requisite conditions, all quite well-known, are the fecundity principle, heritable variation, and finiteness of accessible resources. Dennett, who does not cite Popper, notes the *if–then* logic of natural selection, and, pointing out that algorithms are based on *if–then* logic, asserts that natural selection is an algorithmic process. But this conclusion simply does not follow. Dennett's assertion is based on the category error that follows from conflating the model with the thing being modeled (call this the *modeler's fallacy*).

The error follows from the assumption that if a rule-based system, such as a model or mechanical device, simulates or captures the behavior of some part of the world in some sense, then that part of the world is itself a rule-based system or mechanical device. The illegal or erroneous move that Dennett repeatedly makes is from "can be considered as an algorithmic process," as in modeled with an algorithmic process, to "*is* an algorithmic process." But this is an unsuccessful sleight of hand. The fact that every lawful process can be simulated by an algorithm using an *if–then* set of rules does not mean that lawful processes entail algorithmic procedures, or sets of rules to occur. In fact, the complete opposite is true. A defining property of a lawful, as opposed to a rule-based, behavior is that, as with the case of natural selection, lawful behavior follows directly from initial conditions and the respective law or laws, without a list of procedures or instructions required for its occurrence.[6]

"Won't *any* process be an algorithm?" asks Dennett (1995b). "Is the surf pounding on the beach an algorithmic process? Is the sun baking the clay of a dried-up river bed an algorithmic process? The answer is that there may be features of these processes that *are* best appreciated if we consider them as algorithms!" (p. 57) he says. But the faulty segue is obvious because Dennett's answer avoids answering his own question, which is "won't any of these processes *be* an algorithm?" not "can any of these processes *be considered* as an algorithm?" The answer to the actual question is a simple no. Dennett also gives the example of annealing a piece of metal, and, finally comes to natural selection itself, which is no more an algorithm or an algorithmic process than any of the others. All of these processes may certainly be modeled (for better or worse) by algorithms, but there are no grounds at all for asserting that a single one of them *is* an algorithmic process.

"The pattern of cracks that appear in the sun-baked clay" says Dennett, "may be best explained by looking at chains of events that are not unlike the successive rounds in a [chess] tournament" (p. 57). That they are "best explained" is certainly false because the main point crucially avoided in this and other like statements made by Dennett is that both a model of this kind and a chess tournament are rule based, while the dynamics producing the patterns in sun-baked clay are not. The main point to summarize is precisely that the patterns that appear in sun-baked clay do not require algorithms, or sets of instructions, to appear, but are a kind of spontaneous order that follows directly from laws and initial conditions. Likewise, natural selection simply occurs lawfully or necessarily, as Popper and others have

[6]To avoid a possible confusion in advance, it should be pointed out that on the distinction between rules and laws used here, cultural systems are rule-based systems and cultural "laws" (e.g., speed limits on highways, or laws against theft or sodomy), are "rules" in contrast to the universal laws of physics (e.g., the "law of gravity," or the "laws of thermodynamics"). In principle, rules can, and often are, in practice, readily broken, although in principle, laws never are, and as far as we know, never have been broken.

pointed out, if the conditions of the fecundity principle, heritable variation, and the finiteness of space–time are present—no step-by-step set of instructions, or rules is executed, needed, or present.

Life Is Autocatakinetic, Not Algorithmic (Your Grandmother's Grandmother Was Not A "Macro")

As noted, the roots of Cartesian dualism and the postulates of incommensurability in modern science, where a "dead" or deficient material or physical world is contrasted with an active, ideal, or immaterial world, go back through Plato to the Pythagoreans. The dualistic doctrine of the Pythagorean Brotherhood, a mystical sect founded in the Greek city of Croton in the 6th century B.C., pitted form against matter, or the ideal against the physical, holding that the physical or material world was transient and illusory, whereas what was true, the true stuff or substance of the world, and that which motivated it, the active principle, was a hidden world of ideal, eternal or immortal, immaterial forms. The Pythagoreans construct and motivate "physical bodies out of things having no mass," wrote Aristotle (Philip, 1966, p. 84), and "[i]n this respect they seem to be discussing some other universe than ours." In the same tradition, Anaxagoras, a prominent dualist following the Pythagoreans, and known particularly from Aristotle's famous criticism of him, held that mind (*nous*), a kind of universal substance, although remaining absolutely separate, permeates the otherwise inactive or inert matter of the world and orders it. Aristotle's (1961) criticism was that Anaxagoras used mind in his theory "as a sort of *deus ex machina* to produce order" (p. 63) or anything else for which he did not have a real explanation.

Subsequently, the Greek atomists, through the writing of Democritus, proposed a dead physical substrate of propertyless particles that had to be ordered and animated by "soul particles," and later, Plato, whose Pythagorean roots are well-recognized, proposed that the perceived world of change (Becoming), which he took as illusory, results from the action of true reality (Being) comprised of immortal, immaterial, or ideal, forms acting on a dead material substrate (Not-Being). The problem of how eternal or immortal, and hence static forms could first act, how something conserved could be implicated in animating the world, and how immaterial forms, even if they could act, could in any case interact with a material substrate—the general problem of dualist interactionism—forced Plato to invent the "Demiurge" (or artificer).

What the Demiurge did was miraculously bridge the form–matter dualism and, in Plato's (1949) words, "finding the whole [world in a] disorderly fashion, out of disorder [brought] order" (p. 13). The mechanical world of Descartes, built out of a "dead" material substrate incapable of ordering itself, was the repackaged offspring of this dualist tradition with "mind" as the active ordering agent, a view expanded by Kant and Blumenbach to include a special vital principle or force peculiar to living things. In the Dawkins-Dennett repackaging, the job is done by "macros" or algorithms, immaterial and immortal forms in true Pythagorean tradition, "abstract instructions" existing, in Dawkins' (1995, p. 8) words, in "time not space," working on a dead physical substrate that inherently goes otherwise to disorder.

As noted earlier, Dennett (1995b) asserts that "if Darwin is right, your great, great ... grandmother was a ... macro. ... That is the unavoidable conclusion of the previous chapters ... you descended from macros" (p. 206). According to Dennett, "we all know it well in outline: before there were bacteria with autonomous metabolisms, there were simpler quasi-living things, like viruses ... viruses ... 'do things' ... they reproduce or self-replicate. ... Computer programmers call a cobbled together fragment of coded instructions that performs a particular task a 'macro,' so I propose to call these pioneers macros to stress that ... they are ... bits of program or algorithm ... like computer viruses" (p. 156). "It is now clear," Dennett writes, "that they spent the better part of a billion years evolving on Earth before there were any [truly] living things [things with autonomous metabolisms]" (p. 206).

In the first place, this scenario, "we all know well," a scenario developed from Dawkins, is empirically false. Early life, or "quasi-life" as Dennett describes it, would have had to have evolved under water to escape the intense ultraviolet rays hitting the Earth at that time due to the absence of a protective ozone layer atop the atmosphere (that came into being with the ascendancy of global oxygen levels beginning some 2 billion years ago). This presents a fatal problem for Dennett's scenario. The Earth is about 4.6 billion years old, and until roughly 4 billion years ago, as a consequence of meteoric bombardment, it was too hot for oceans to form (e.g., Schopf, 1983; Cloud, 1988). Bodies of water, in other words, would have evaporated. But 4 billion years ago is just when prokaryotes (bacteria) are known to have appeared on Earth, namely, as soon as the Earth was cool enough to support oceans (e.g., Cloud, 1989). Thus, there was no 1-billion year window for the imaginary world of "naked algorithms" that Dennett asserts got life going. In addition, even if there were such a billion-year window, there is no other evidence that such a world of naked algorithms ever existed.

Life as metabolic. Beyond the aforementioned empirical problems, there is a major theoretical problem with Dennett's scheme, the understanding of which has profound importance with respect to the understanding of living things and their relations to their environments, and the epistemic dimension of the world in general. In one sense, the DNA strings that are typically used in the replication or reproduction of living cells are like computer viruses: just as no computer virus has ever been found to function without a computer, and no computer outside of a human cultural system, no DNA string, or biological virus, has ever been known to function independently of a living metabolizing cell. DNA strings or molecules, or viruses (whether computer or biological), are not alive.

In short, life at its origins was metabolic, or, using the more technical term "autocatakinetic," not algorithmic. Autocatakinetic systems are process structures constituted by the continuous motion or flux of their components through the use, or breakdown, of environmental energy potentials or resources.[7] Figure 1 shows a schematic drawing capturing the general minimal ontology that an autocatakinetic system entails. A point that should be underscored is that autocatakinetic systems are defined in relation to or through their environments—they have no existence, either real or imaginary, separate from their environments. All living things are autocatakinetic, but not all autocatakinetic systems are living. Flames, tornadoes, and dust devils are all autocatakinetic systems, dynamically constituted through the continuous flux of their components in the dissipation of environmental potentials, but they are not living. Living systems are a kind of autocatakinetic system. They are replicative systems—autocatakinetic systems that produce components by replication as part of their autocatakinetic cycles, and the simplest sustainable case, to restate, is a single cell and its nonequilibrium environment. Viruses—biological or computer—algorithms, and so on, are not autocatakinetic systems, and consequently, are not alive.

The root idea of autocatakinesis goes back at least to Heraclitus (536 B.C.), who characterized the world as a process of continual flow ("all things flow") and its objects as constituted by a generalized metabolism or combustion. Fire, as Aristotle (1947) wrote centuries later in *De Anima*, elaborating on the ideas of Heraclitus and stressing the active agency and generalized metabolism or self-organizing properties of such systems, "alone of the primary elements [earth, water, air, and fire] is observed to feed and increase itself" (p. 182). The discovery by Priestley, Lavoisier, and Cavendish, in the 18th century, that the metabolism of living things was a form of combustion—that the autocatakinesis of living things was maintained by the burning of organic materials in the presence of oxygen—deepened this understanding. In addition, what Priestley and Lavoisier knew they discovered with the discovery of oxygen was, in fact, as biogeochemical evidence gathered in the middle and last part of this century has confirmed, only the tip of the iceberg. In particular, the atmospheric oxygen

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[7]More precisely, an autocatakinetic system is a system that maintains its "self" as an entity in relation to, and distinguished from, its environment by a set of nonlinear (circularly causal) relations constituted through the coordinated motion of its components in the dissipation or breakdown of field (environmental) potentials (or resources) (from *auto-* "self" + *cata-* "down" + *kinetic*, "of the motion of material bodies and the forces and energy associated therewith" from *kinein*, "to cause to move"; Swenson, 1991a). The words "autocatakinetic," "self-organization," and "spontaneously ordered" are used synonymously in this article, but it should be underscored that the latter two words are also used to refer to patterns that emerge in computer simulations. A more appropriate term in this case might be "programmed self-organization" because although these systems may (or may not, as the case may be) provide useful models of "real-world" self-organizing, they are, in fact, rule-based, externally programmed systems and to conflate the two indiscriminantly is to commit the "modeler's fallacy" discussed in the text. Consistent with the views expressed in this essay, Dyke (1996) has cautioned against the neo-Pythagoreanism that follows from such a conflation.

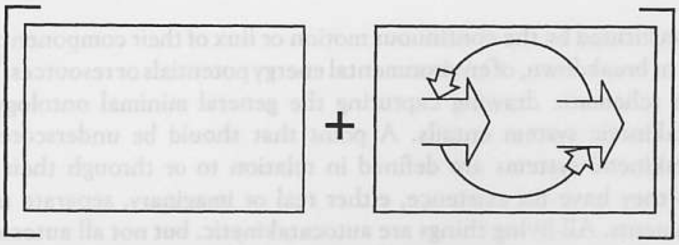

FIGURE 1 A schematic of the conjunction capturing the generalized minimal ontology of an autocatakinetic system. The left side represents the conservation out of which the autocatakinetic system and environment relation arises, and through which it is maintained. The right side shows the environment–autocatakinetic system relation. The large arrows capture the irreversible minimization of potential (the irreversible production of entropy) in the flow of the conservation (energy) from source to sink, and the small arrows capture the continuous circular relations by which the autocatakinetic system is constituted.

that has kept the fire of life burning, while at the same time paving the way for forms to evolve increasingly farther from equilibrium (e.g., eukaryotes, multicellular eukaryotes, complex eukaryotic social systems, human cultural systems), was put into the atmosphere, and maintained by life itself as an autocatakinetic process at the planetary level.[8]

Returning specifically to Dennett's assertions and to the absence of a billion-year window for the algorithmic world Dennett imagines, there is no evidence that life was or could have been anything but autocatakinetic from its beginnings. Viruses, computer algorithms, strings of DNA, or Dennett's hypothetical macro ancestors do not meet the minimal criteria for living things. As Margulis and Sagan (1995) have rightly emphasized, like the dependency of computer viruses on working computers, biological viruses have no meaning or existence without the autocatakinetic systems within which they are replicated.[9] The assertion of an ancestral world of quasi-living algorithms is a figment of Dennett's imagination that flies in the face of the empirical facts. The claim that your great, great ... grandmother's grandmother was a "macro" or algorithm is a category error. Macros and grandmothers are not the same kinds of things. *Grandmothers are autocatakinetic; macros and viruses are not.*

[8]With meager evidence, both Chambers and Spencer anticipated the now empirically substantiated fact that evolution on Earth is a planetary process, that there had been little or no oxygen on the early Earth, and that there is a relation between increasing atmospheric oxygen levels to the production of higher states of living order.

[9]Margulis and Sagan use the term "autopoietic" rather than "autocatakinetic," but their connotation is consistent with the meaning of the latter. The problems with the former, whose proper definition does not have the same connotation, and that is rooted in an anti-ecological solipsistic epistemology, are discussed elsewhere (e.g., Swenson, 1992, in press-c; for discussion of "closed circle theory" in general,

Invoking Algorithms to "Explain the Active Agency in the Universe" Is Illegitimate Teleology

As discussed earlier, the use of active, immaterial, or ideal ordering devices to bring agency, end-directedness, or intentional ordering into an otherwise postulated "dead" physical substrate, goes back at least as far as the Pythagoreans and is the basis in modern times of Cartesian metaphysics and the mechanical world view. Dennett's selfish algorithm theory, an elaboration of Dawkins's selfish gene (or "replicator") theory, is this same idea in contemporary packaging. The physical world, the "river that flows downhill," is taken to go spontaneously toward "death," a state of maximum disorder, and the "river that flows uphill," the active, end-directed striving, the *telos* of living things and their evolution, is the consequence of the active programming by algorithms, or "replicators," ordering the "dead" physical world toward their own ends. Until the "invasion of human brains" by *memes* (Dawkins's name for cultural "replicators" or ideas), Dennett's explanation for the origin of "mind" or consciousness, "there were no forces whose principal beneficiary," according to Dennett (1995b), "was anything else" but genes (p. 370). "Life," in Dawkins's (1995) words, "is just bytes and bytes of digital information ... and [evolution] a river of information ... of abstract instructions for building bodies, and ... all living things ... are survival machines programmed to propagate them" (p. 19).

According to Dawkins and Dennett, to use Aristotle's (Grene, 1966/1974) words, evolution is "for the sake of something" (p. 229), and that something, the end served, is the replication of genes (and with culture, memes), or algorithms, in Dennett's terms. Although such replicators require a material vehicle for their expression (e.g., a DNA molecule), the replicator, per Dawkins and Dennett, is not equivalent to the vehicle. Vehicles die, although the replicators that inhabit them, which "live" on from one generation to the next, are potentially immortal. A measure of the success of a gene and "the quantity," according to Dawkins (1995), "that is being diligently maximized in every cranny of the living world is, in every case, the survival of the DNA responsible for the feature you are trying to explain" (p. 120).

Following the numerous landmark discoveries of molecular biology during the middle of this century at a time when the computer revolution was getting under way, and given the Cartesian-Kantian background assumptions built into Darwinian theory, it became widespread among the proponents of Darwinian theory to ascribe the active agency of living things to the genetic programs they were said to carry. Mayr (1969, 1976), for example, adopted the word "teleonomy," defined as end- or goal-directedness due to the operation of a program, to refer to the end-directedness of living things. The neo-Pythagoreanism of Dawkins and Dennett that promotes genes to the status of animistic "replicators" extremizes this already problematic view. Although it is presented in such a way to make it seem to follow from the facts of molecular biology, it does nothing of the kind. Under the rubric of "replicators" ("algorithms," "macros," or "pieces of program"), it takes "abstractions that have been transformed by fetishism and reification into realities with an independent ontological status," in the words of Levins and Lewontin (1985, p. 150), and puts them at the center of its theory. The result of this teleomechanical smuggling is an illegitimate teleology that conjures end-directed agency out of thin air and puts it in the one place it cannot be.

The myth of the selfish replicator. As underscored, living things are autocatakinetic systems that produce components by replication, and replication never occurs outside the context of the autocatakinetic system plus its nonequilibrium environment as a whole. More particularly, reviewing briefly, replication is used by living things for the synthesis of larger molecular components, or polymers, from smaller molecular components, or monomers (usually consisting of 50 atoms or less) with the principal cellular polymers produced in the autocatakinetic cycle being proteins and nucleic acids. In both cases, the production of polymers proceeds with the sequential addition of monomers according to a DNA template so as to create a linear string that, in the case of proteins, spontaneously folds into a three-dimensional functional structure. The functional form of nucleic acids, of which there are two main kinds, deoxyribonucleic acid (DNA), and ribonucleic acid (RNA), remains a linear polymer. Proteins are built from monomeric amino acids of which there are twenty different kinds, and DNA and RNA are each built from four different kinds of monomers called nucleotides (e.g., see Darnell, Lodish, & Baltimore, 1986).

In the production of proteins, a complementary RNA copy (mRNA, or messenger RNA) is first made from the DNA template (*transcription*), and then amino acids are strung together on ribosomes in a different part of the cell according to its nucleotide sequence (*translation*). Typically each amino acid is specified by a particular sequence of three RNA nucleotide bases (a *codon*). Following the discovery of DNA structure and its relation to the component production in cells, as a consequence of elucidating this translation process, it became popular in the 1950s to say that DNA, or the genes that its linear sequences constitute, "codes" for proteins, and it also became popular to talk of DNA (or genes) as constituting a "blueprint," coded instructions, or "program" for building the living things that contained it. The smell of autonomous agency became stronger when, because the DNA template in a cell is used as a template for the replication of DNA itself, DNA came to be called a "self-replicating" molecule. The idea that living things are built out of passive matter by DNA programs that are also self-replicating, leads to the neo-Pythagorean selfish replicator (or algorithm) theory of Dawkins and Dennett.

Putting aside the problem of dualist interactionism that fatally wounds all such schemes, living things do not contain blueprints or programs in any ordinary sense of the words, and the putative "replicators" of Dawkins and Dennett are a myth—the result, as Levins and Lewontin have correctly asserted, of fetishism and reification (see also Fleischaker, 1990, & Goodwin, 1982). DNA molecules in cells constitute a very particular kind of cellular component that, along with proteins among other things, are used as part of the end-directed autocatakinetic component-producing system as a whole. The entire cell-environment system is end-directed and active, but if there is any part of it that is static, inert, or inactive relative to the rest of the system, it is the DNA or genes. The myth of the replicator has been pointed out by various critics of the idealist reductionism of selfish gene theory. The DNA of living things, as Goodwin (1994) has expressed in straightforward terms is simply "not self-replicating; it is not an independent 'replicator'" (p. 35). Contrary to the popular conception, writes Lewontin (1992), "that genes *make* proteins, and that genes are *self-replicating* ... genes can *make* nothing" (p. 48). Component production or replication, including the replication of DNA, is a function of the entire autocatakinetic system as a whole and not of a particular molecule in the cell. Genes "cannot make themselves any more than they can make a protein," and by referring to them "as self-replicating," continues Lewontin, "we endow them with a mysterious, autonomous [and illegitimate teleological] power" they simply do not have (p. 48; see also Swenson, 1990b).

Not only is it the case that DNA is not a self-replicating molecule, that, like proteins, is replicated and produced as part of the component production process of the autocatakinetic system as a whole, but within this system it is "proteins," as Darnell et al. (1986) have written in their authoritative text, *Molecular Cell Biology*, that "are the active working components" of the cell, not the DNA molecules (p. 107). It is proteins, in the form of polymerases, that carry out component replication or synthesis of both protein and nucleic acids. In addition, although it is true that DNA provides a crucial template used in the component production process, it is nothing like a blueprint, set of instructions, or program for building a living thing. It does not even specify the three-dimensional coordinates of a single protein let alone provide instructions as to how to put proteins together to form a living thing or even a part. Even the linear sequence of amino acids that the template does specify is typically incomplete and requires modification by the cellular dynamics, by proteins (e.g., by cutting and splicing) after it is released from the ribosomes.

To say that the DNA contains a blueprint, recipe, or program would completely change the meaning of these terms in the usual (artifactual) context in which they are normally used. It would be as though instead of what is usually thought of as a blueprint (typically explicit instructions for building a house or other structure), an architect furnished only a list of raw materials to the contractor or client. What would be missing would be the instructions for assembling the materials into a functional three-dimensional product, a subject on which the DNA in cells is entirely mute. In the case of living systems, this is provided by the cellular dynamics of autocatakinetic systems, self-organizing systems that, in contrast to artifactual ones, assume their dynamic forms following from initial conditions and laws, principles of self-organization, and not, in general, from rules or any explicit representation or set of instructions. What autocatakinetic systems in general do is utterly fantastic in the context of artifactual or rule-based (algorithm based) systems: They not only build, repair and maintain themselves, but, in the case of living things, go out and seek the raw materials to keep this dynamic process going.

The function of DNA (like the words on this page) depends on its inactivity. "DNA," as Lewontin (1992) has written, "is a dead molecule, among the most nonreactive in the living world. That is why it can be recovered in good enough shape to determine its sequence from mummies" (p. 33). Biological viruses, which evolved as part of the complex process of gene exchange by which the prokaryotic world developed and has maintained the Earth's biogeochemical cycles (the price of keeping the system loose and adaptable), are simply a dead, and not very interesting, "mixture of chemicals," as Margulis and Sagan (1995, p. 24) have put it, without an environment of active end-directed, replicative autocatakinetic systems. Likewise, computer programs or algorithms, like the words on this page, are dead and meaningless without the autocatakinetic cultural systems of which they, and the computers that run them, and other artifacts are component productions.

Finally, as discussed more fully later, replicative ordering provides the means for the world to build dynamical systems able to access otherwise inaccessible space–time dimensions, in particular, to build dynamical order from discontinuously located potentials (Swenson, 1991b; Swenson & Turvey, 1991). Toward this end replicative systems, whether living systems in general or cultural systems (second- and third-order autocatakinetic systems, respectively[10]), require "a set of internal constraints (such as the words on this page or DNA strings) that are discrete, sequential, and rate-independent relative to the rest of the autocatakinetic cycle" (Swenson & Turvey, 1991, p. 343). This insight was first expressed by Polanyi (1968), who noted that the "order [of the linear sequences of a DNA molecule] is not due to the forces of potential energy," (p. 1309) or, more accurately, as we understand it now, to local potentials. The order of the sequences of such constraints, as Polanyi pointed out, such as the words on this page or the sequence of base pairs in a DNA string, is arbitrary with respect to local potentials. Namely, the strings or sentences of equal lengths, for all practical purposes, take the same amount of potential energy to produce (*write*) or use (*read*).

The major point of relevance here is that the function of DNA, like the letters or words on this page, depends precisely on the local thermodynamic or energetic equivalence of the sequences. In different terms, the function of DNA, like the function of the words on this page, as with all other rule-based systems (e.g., recipes, blueprints, programs, or algorithms) depends on the fact that any sequence can be exchanged with any other without any local energetic consequence. It is the stability of the DNA molecule, in other words, regardless of the sequence—its inertness, or utter inactivity, or "deadness" on which its function crucially depends, but, alas for the reductive idealists, it is this property of

[10]First-order autocatakinetic systems being nonreplicative, hence nonliving, autocatakinetic systems such as tornadoes, hurricanes, and dust devils.

deadness or inactivity that also disqualifies it a priori from the role of active agent that they would like to attribute to it.

The "memic theory of mind." In addition to an assumption of the incommensurability between living things and their universal context or between biology and physics, one of the major shortcomings of Darwinian theory is its failure to address cultural evolution. If the "almost universally adopted definition of evolution [is] a change in gene frequencies" within a population as a result of natural selection, as Mayr (1980, p. 12) has written, and if this is, today, what is meant by Darwinism, then Darwinism, by definition, can have little if anything at all to say about cultural evolution. Cultural ordering is replicative, but what is passed on from one cycle to the next is not principally genetic information but, loosely put, ideas. On the canonical view of contemporary Darwinism, the term "evolution" is thus misapplied with respect to cultural as well as nonliving (*physical*) processes. "Cultural 'evolution,'" writes Dawkins (1986), "is not really evolution at all if we are being fussy and purist about our use of words" (p. 216), although in the *Selfish Gene* (1976), he asserted that biological and cultural change nevertheless proceed according to the same principles. It is just the kind of "replicators," he says, that are different, and he coined the word "meme" to refer to the cultural kind. Later, in the *Blind Watchmaker*, writing that he does not consider himself informed enough on cultural change to write about it, Dawkins backpedaled somewhat to say that the comparison between biological evolution and cultural evolution, which he says is not really evolution at all, "can be taken too far if we are not careful" (1986, p. 361).

Dennett, asserting what amounts to the 1976 position of Dawkins, used explicitly to provide an account of the origin of "mind" (or *consciousness*) in nature, goes well beyond the received view of contemporary Darwinism and Dawkins's present position as well. "Just as genes propagate themselves in the gene pool by leaping from body to body via sperm or eggs, so memes propagate themselves in the meme pool by leaping from brain to brain" (Dennett, 1995b, p. 346), and just as a living thing (an "organism") is said to be simply a gene's way of making more genes, on the memic view, according to Dennett, "a scholar is just a library's way of making another library" (p. 346). As the evolution of life is said to be for the good of genes, the evolution of culture is said to be for the good of memes—the *telos* of life is said to come from genes, whereas the telos of culture, of "mind," from memes. Dennett attacks Lewontin's criticism that the memic view "presupposes a Cartesian view of mind" (p. 368). But this is exactly what it does with the dead world of physics it assumes, and the ideal agents it invokes to animate it.

The memic "explanation" of "mind," like the replicator account of the intentional ordering of living things in general, is no explanation at all. Instead, with the imaginary ideal agents it conjures under the rubric of memes, it simply attempts to smuggle in what it otherwise purports to explain. Like its genetic replicator counterpart, it suffers fatally from the old problem of dualist interactionism, and is empirically and logically untenable. Culture theory, as Dawkins himself acknowledges, is technically outside of the realm of Darwinism contemporarily defined, but well beyond this, Dennett's claim that selfish meme theory is a "through-and-through Darwinian version of mind" (p. 368) is false for the same reasons that the same claims made about macros or selfish bits of DNA are false. Darwin's theory was about living, reproducing, metabolizing things, not about animated bits of program or ideal "replicators" building living things toward their own ends.

More substantively, the logical and empirical deficiencies of the memic view of mind are apparent in the assertion in Dennett's summary sentence that "the invasion of human brains by culture, in the form of memes, has created human minds" (1995b, p. 369). The idea that human brains existed prior to human "minds" is certainly preposterous. From an evolutionary standpoint, this assertion is empirically false, sufficient in itself to reject the theory. Yet even if this were not an empirically decidable issue, as with all dualist idealist schemes, it is a radically unparsimonious, impossibly hard to imagine theory. Most striking, however, with respect to the current discussion, is its anti-evolutionary premises. It assumes human brains and memes appeared independently of each other, independently of cultural autocatakinesis, and the selection pressure internal to it—that they appeared, in effect, by miracle. But "memes" (ideas) have no such independent existence and did not "invade" brains to create culture or mind—cultural ideas, and their meanings, like genes and their relation to the autocatakinesis of living things in general, do not exist outside the circular relations that define the autocatakinesis of culture.

From the evolutionary record, it is uncontentious that cultural ordering was certainly a prehuman process. Brains and ideas did not evolve separately or appear suddenly and separately with the latter "invading" the former to create "minds," but together as part of an ongoing evolutionary process. The autocatakinesis of cultural ordering goes back at least as far as the Australopithecines, who used tools some three million or more years ago with the relevant cultural knowledge being passed on or replicated by simple apprenticeship or imitation (e.g., Campbell, 1985). Cultural ordering continued as a process of continuous autocatakinesis from the Australopithecines through Homo habilis and Homo erectus, and then with modern humans. The evolution of the brain, which went from roughly one one-hundredth of the body weight of an Australopithecine to one forty-fifth in modern humans, along with the articulation of the larynx, vocal cords, and tongue that made possible the linguistic skills on which the cultural ordering (and ideas) of modern humans depend, occurred internal to this ongoing autocatakinetic process. Human beings (and human minds) developed as a product of brains and ideas evolving together as part of the evolutionary component production process of cultural autocatakinesis.

The Idea That Evolution Is for the Benefit of Potentially Immortal Replicators Is False for a Number of Reasons

Perpetual motion. Dawkin's idea, borrowed by Dennett, that evolution is for the benefit of potentially immortal replicators—that the *telos* of evolutionary ordering is explained by and serves potentially immortal replicators, flags the idealist core of Dennett's scheme and the separation of his abstract replicators from real-world physics and cosmology. From the standpoint of physics, energy is conserved or "potentially immortal" (immortal as far as science knows), but replicators, on the contrary, except those existing ideally outside the laws of physics (and thus, regardless of the assertions of Dawkins and Dennett, being unobservable and unknowable to science) surely are not immortal, or even potentially so. Beyond being autocatakinetic, real-world replication is an irreversible process, meaning it requires the dissipation of potential energy (or the production of entropy) to occur. Denial of perpetual motion of the first and second kind is taken by many to be the most unassailable fact of physics (e.g., Eddington, 1958). Irreversible process, both locally, and on a cosmic scale, in principle, and empirically as far as anyone knows, always come to an end at some point. To make the claim for the potential immortality of replicators, one would have to come up with a cosmic perpetual motion machine to justify the theory. Without it, the theory is premised on ongoing miracles.[11]

Life at its terrestrial foundations is a planetary prokaryotic process. Another problem with the idea that living things die while replicators persist, the case of the salmon swimming upstream to spawn being an exemplar for Dennett, is that it is premised on the erroneous anachronistic view that life at its core is eukaryotic. Darwinian theory is largely a discussion about the kind of life that became visible after the Cambrian, particularly living things that are somewhat like us, namely, sexually reproducing eukaryotes, and especially animals, with discrete life span and body size. But such creatures, which have appeared only during the last 15% of evolution on Earth, are not at all typical in these respects of life on Earth writ large. The dominant form of life, in the sense of making up not only the greatest amount of biomass over evolutionary time, but establishing, and maintaining, life as a continuous autocatakinetic planetary process on which the eukaryotic forms at the heart of the Darwinian discourse depend, is prokaryotic (bacterial; Margulis, 1981).

[11] Although radically at odds with modern science, in contemporary form, in fact, this is the general view maintained by the Pythagoreans and later Plato. In this case, the huge burden of proof is on Dennett and Dawkins.

If humans and other eukaryotes were taken off the Earth, prokaryotic life would still carry on and evolve, but if prokaryotes were taken off the Earth, all the rest of life would die. Prokaryotic life, reproducing by fission of one individual into two, has been continuous, as far as anyone knows from its beginnings on early Earth, and to this extent has never "died." Life on Earth from its beginning has been a single continuous process of autocatakinesis that developed to a coherent planetary scale at least by 2 billion years ago when the redox state of the Earth became primarily oxidative rather than reducing. All the higher ordered forms of life that are the typical objects of Darwinian study, as well as human cultural ordering, are absolutely dependent on the prior and continued persistence of the planetary system as a whole for their existence. The idea that living things die while replicators persist is based on a reductionistic conception of life that takes life out of its autocatakinetic context and seeks to deny the empirically undeniable and fundamental planetary nature of life. Although countless numbers of genes have come and gone, life, as a planetary process of autocatakinesis, has been functioning without interruption for some 4 billion years, and in principle will remain so as long as the solar system, and the Earth system in particular, remain within tolerance ("potentially immortal within tolerance"). That Darwinian theories would seek to deny or avoid addressing the fact of planetary evolution is expected by virtue of the fact, discussed later, that an account of planetary evolution is beyond the reach of its explanatory core.

Which replicators? Finally, the idea that evolution is for the benefit of selfish replicators as captured by Dawkins's (1995) statement that "[t]he great universal Utility Function [a term he borrows from Dennett], the quantity that is being diligently maximized in every cranny of the living world is, in every case, the survival of the DNA responsible for the feature you are trying to explain" (p. 120), flags another major problem. If evolution is for the benefit of replicators, then this begs the question of "which replicators?" and Dawkins' answer from the above is those responsible for the feature you are trying to explain. But, even putting aside the subjectivity of such an observable (the replicator responsible for the feature you , and not I, for example, are trying to explain), how can this be? Suppose the feature you are trying to explain is one that went extinct. How can it be that evolution was acting to maximize the replicators responsible for this feature? Clearly, evolution acted to minimize them—going extinct, or to zero, being the extreme case, and 99% of all species on Earth, it should be noted, are believed to have done so, and so presumably a good portion of their genes. The problem with the claim concerning a universal utility function is a particular instance of the problem for Darwinism in general with universal statements, or statements about what evolution as a whole is about, or the directed nature of evolution. Evolution for Darwinian theory is about fitness, but fitness is relativized to members of breeding populations. The fitness of a member of one breeding population (e.g., a zebra) cannot be compared to the fitness of a member of another breeding population (e.g., an amoeba), and this makes fitness an incommensurable observable with respect to evolution writ large (e.g., see Fisher, 1930/1958; Sober, 1984; Swenson, in press-a; Swenson & Turvey, 1991). Darwinian theory has no observables from which it can draw conclusions or make statements about evolution as a whole.

THE ACTIVE NATURE OF LIVING THINGS DOES NOT DEFY UNIVERSAL LAW BUT FOLLOWS DIRECTLY FROM IT

Living Things as Things That "Defy the Laws of Physics"

The idea that life in general, and "mind" in particular, is organized in the service of a battle against the second law of thermodynamics is central to Dennett's idealist reductionist scheme in which extra-physical orderers in the form of selfish algorithms are required to bring agency, or active, end-directed ordering, into a world otherwise collapsing to disorder. In fact, in answer to his own question "What then are living things?" he says that they are things that "defy" the second law of thermodynamics by orchestrating a "systematic reversal" of it (1995b, p. 69). The idea that the active agency of living things captured in the fecundity principle, or the intentional dynamics of living things, or "mind" in nature, works against the second law follows, in modern times, from the bifurcated mechanical world view coming out of Cartesian metaphysics, and a physics that was built, in effect, to justify it. This section reviews the newer understanding of the relevant laws of thermodynamics and shows why, rather than working against the universal principles of physics, living things and their intentional dynamics, or the epistemic or psychological dimension of the world, are a direct manifestation of them. This new view undermines the old bifurcated Cartesian view at the core of Dennett's theory, obviating the need for ad hoc ordering agents, and situates living things and their environments, knower and known, as parts of a commensurable world, explicated by a deeper, more robust, and comprehensive evolutionary perspective.

The First and Second Laws of Thermodynamics

"Entropy," says Dennett (1995b) in *Darwin's Dangerous Idea*, "is simply disorder, the opposite of order," and according to the second law, "things run down" or become more disordered (p. 68). What he fails to mention, however, is that this meaning of entropy comes out of Boltzmann's statistical interpretation of the second law, a *hypothesis* that Boltzmann put forward in an attempt to save the mechanical or Cartesian world view. It is not the meaning of entropy or the second law as classically defined. The second law as classically stated by Clausius (1865) and Thomson (1852a), who formulated it following the work of Carnot (1824/1960), says nothing about order or disorder at all. It is about minimizing the "availability," as Carnot called it, or potential of energy for doing work.

Following the work of Davy and Rumford, the first law was formulated by Mayer, then Joule, and later Helmholtz in the first half of the 19th century with various demonstrations of the equivalence of heat and other forms of energy (e.g., see Thomson, 1852b; Singer, 1959; Schneer, 1960; Swenson, in press-c). The law was completed in this century with Einstein's demonstration that matter is also a form of energy. The first law says that (a) all real-world processes consist of transformations of one form of energy into another (e.g., mechanical, chemical, or electrical energy or energy in the form of heat), and that (b) the total amount of energy in all real-world transformations always remains the same or is conserved (energy is neither created nor destroyed).

The first law was not fully understood until the second law was formulated by Clausius and Thomson in the 1850s. What Carnot had observed some 25 years earlier was that, as he explained it, like the fall of a stream that turns a mill wheel, it was the "fall" of heat from higher to lower temperatures that motivates a steam engine. With the recognition that it was the potential to "fall" from hot to cold, or from a higher to lower place that motivated the flow of the stream, the turning of the mill wheel, or the motion of the steam engine, came the recognition that with these actions the potential was irreversibly destroyed, or dissipated, as Thomson (1852b) would put it. Realizing that the active principle, if based on dissipation, could not be energy, which is conserved, Thomson and Clausius recognized that there were two fundamental laws in operation and showed how they were related. Clausius coined the word "entropy" to refer to the dissipated potential, and the second law states in its most fundamental form that all natural processes proceed so as to maximize the entropy (or equivalently minimize or dissipate the potential of a system), although, at the same time, energy is entirely conserved.

The first and second laws of thermodynamics are thus symmetry principles that sit above the other laws of nature, as, in effect, laws about laws, or laws on which the other laws are dependent (Swenson, 1991b; Swenson & Turvey, 1991). The first law expresses the time-translation symmetry of all natural processes, that which remains the same in all past, present, and future states, and the second law expresses the broken-symmetry of the natural world, providing, in a world that is out of equilibrium, as our expanding universe is, a nomological basis for distinguishing past, present, and future. The balance equation of the second law, expressed as $\Delta S > 0$ says that in all real-world processes, entropy always increases.

In sharp contrast to the "dead" mechanical world view of Descartes and Newton, the active, end-directed nature of the world was stressed by Clausius (1865) in his statement of the first two laws of thermodynamics: "The energy of the world remains constant," he said, while "the entropy of the world *strives* to a maximum" (p. 400; italics added). Entropy maximization supplies what can be thought of as a final cause, in Aristotle's terms, of all natural processes—"the end to which everything strives and which everything serves" or "the end of every motive or generative process" (Bunge, 1979, p. 32; see also Salthe, 1994; Swenson, 1990a, 1991b; Swenson & Turvey, 1991). The active, end-directed (going toward an end, no "director" implied) nature of the second law is intuitively easy to grasp and empirically easy to demonstrate.

Consider a glass of hot liquid placed in a room at a cooler temperature. The temperature gradient or difference in temperatures in the glass-room system constitutes a potential, and a flow of energy in the form of heat, a "drain" on the potential, is spontaneously produced from the glass (source) to the room (sink) until the potential is minimized (the entropy is maximized), and the liquid and the room are at the same temperature. At this point, all flows and thus all entropy production stops ($\Delta S = 0$, and the system is in thermodynamic equilibrium. The same principle applies to any system where any form of energy is out of equilibrium with its surrounds (e.g., whether mechanical, chemical, electrical or energy in the form of heat): A potential exists that the world acts spontaneously to minimize. It spontaneously produces dynamics that work to minimize the potential and stops when the potential is minimized. In this precise and rigorous sense, the world is inherently active and end directed.[12]

Boltzmann's Hypothesis and the Second Law as a Law of Disorder: Why "Organic Evolution" Was Thought to Negate "Physical Evolution"

Dennett's idea that living things exist in a struggle against the apparent universality of physical law, that they defy the second law, or live in a battle against it, and so on, follows from Boltzmann's hypothesis of the second law, which was quite different in a number of ways from the universal physical statement of the second law due to Thomson and Clausius (see Swenson, in press-c for further discussion). When

[12]Here I repeatedly talk of minimizing potential synonymously with maximizing entropy because it is oftentimes hard for people to grasp the dissipation of something in terms of a quantity that increases. On the definition given by Clausius, the entropy of a system refers to the unavailability of the energy of a system for doing work, and Tait (Maxwell, 1872/1970) proposed that the sign of the term entropy be switched to make it easier to understand. In this case, entropy would refer to the potential or availability rather than the unavailability, and the second law would have said that the entropy of the world always decreases, or is spontaneously minimized. Maxwell (1872/1970), concurring with Tait, adopted his suggestion, but the original definition was already too widely used and has persisted to this day. Tait and Maxwell were certainly right. It is far more intuitive to think of the second law as expressing the fact that the world acts spontaneously to minimize potentials (or gradients, or the availability of energy for doing work), and for this reason I repeatedly express it this way. The two ways are equivalent.

A further point should be made with respect to the term *entropy*. Because the word was coined by Clausius, it has been given many different, often nonequivalent meanings that have no established relation to the physical statement of the second law at all. It is important that these nonequivalent terms not be casually conflated (see Swenson, in press-c for further discussion).

the second law was first explicitly recognized, its active macroscopic nature presented a profound blow to the dead mechanical world view. Boltzmann's hypothesis, or theory about the second law, grew out of his attempt to save the mechanical view by reducing the second law to the stochastic collision of mechanical particles—to a law of probability. Modeling colliding gas molecules in a box as billiard balls, Boltzmann, following Maxwell, showed that nonequilibrium velocity distributions (groups of molecules moving at the same speed and in the same direction) would become increasingly disordered with each collision, leading to a final state of macroscopic uniformity and maximum microscopic disorder. Boltzmann recognized this state as the state of maximum entropy (where the macroscopic uniformity corresponds to the dissipation of all field potentials or energy gradients). Generalizing the results to the world as a whole, the second law, he said, was simply the result of the fact that in a world of mechanically colliding particles, disordered states are the most probable.

There are so many more possible disordered states than ordered ones, Boltzmann argued, that a system will almost always be found either in the state of maximum disorder—the macrostate with the greatest number of accessible microstates such as a gas in a box at equilibrium—or moving toward it. A dynamically ordered state, with molecules moving "at the same speed and in the same direction," Boltzmann (1886/1974) wrote, "*is the most improbable case conceivable ... an infinitely improbable configuration of energy*"(p. 20; italics added), and from this conception—from the extrapolation of a near-equilibrium gas in a box to the world—came the idea of the second law as a law of disorder. Although Boltzmann (1896/1964) himself acknowledged that his hypothesis had been demonstrated only for the case of a gas in a box near equilibrium, the science of his time (and until quite recently) was dominated by linear, near-equilibrium, or equilibrium thinking, and his hypothesis became widely accepted. In fact, it came to be taken by many to be the second law, and in this sense Dennett's view represents a common and widespread misconception that has persisted from the time of Boltzmann up to the present.

From the conception of the second law as a law of disorder, the active, epistemic or psychological dimension of the world was seen not only as "infinitely improbable," but working in direct opposition to the second law. Likewise, the progressive ordering that characterizes terrestrial evolution as a whole came to be viewed as a process of the ascendancy of increasingly more improbable forms. The active striving of living things captured in the fecundity principle came to be viewed quite literally as an active struggle, a battle, in Dennett's terms, against the second law, against the otherwise supposed universal laws of physics, and with this, the Kantian–Darwinian tradition of radically separating living things and their environments appeared to have a principled grounding in physics. Where the "dead" mechanical world of Newton was just passive with respect to dynamically ordered states or the intentional dynamics of living things, the laws of physics were now thought to be working relentlessly against them. Living things were seen, in effect, as in the business of fighting the universal laws of physics.

Ronald Fisher, whose crucial role in the implementation of the Darwinian revolution during the first part of this century has already been noted, wrote that "entropy changes lead to a progressive disorganization of the physical world ... while evolutionary changes [produce] progressively higher organization" (1930/1958, p. 39). Given the view of the second law of thermodynamics as a law of disorder, it is "no surprise," in the words of Levins and Lewontin (1985), "that evolutionists [came to] believe organic evolution to be the negation of physical evolution" (p. 19). The next section offers a brief review of the new understanding which, in effect, turns the old idea of the second law as a law of disorder on its head. Rather than being anomalous with respect to physical law or universal principles, spontaneous ordering, the intentional dynamics or active striving of living things captured in the fecundity principle, can now be understood instead as a direct manifestation of them. This view dissolves the incommensurability between the otherwise incommensurable "rivers" and with it the ground of Cartesian theories in general and the anomalies that grow from it.

The Law of Maximum Entropy Production or Why the World is in the Order Production Business

An understanding of the nomological basis for the world as active and end-directed was the great achievement of the classical statement of the second law of thermodynamics, but the direction of the end-directedness, particularly in light of Boltzmann's interpretation, appeared to be directly opposite the end-directedness found in psychology and biology—opposite that which is characterized by autocatakinesis, or the river that flows uphill. The problem was partly put aside in the middle of this century when Bertalanffy (1952) showed that "spontaneous order [or autocatakinetic systems] ... can appear in [open] systems" (p. 145) (systems with energy flows running through them) by virtue of their ability to build order through the dissipation of potentials or energy gradients. Following Bertalanffy, and along the same lines, pointing to the balance equation of the second law, Schrödinger (1945), in a distinctly Heraclitean vein, popularized the idea of living things as streams of order that like flames are permitted to exist away from equilibrium because they feed on "negentropy" (potentials) in their environments. These ideas were further popularized by Prigogine (1978), who called such systems *dissipative structures*.

Schrödinger's point was that as long as living things like flames (and all autocatakinetic systems) produce entropy (or minimize potentials) at a sufficient rate to compensate for their own internal ordering, the dynamical reduction in entropy that characterizes their ordered persistence away from equilibrium, then the balance equation of the second law would not be violated. Thus dynamic order, or autocatakinesis, *can* arise spontaneously from the Bertalanffy-Schrödinger-Prigogine perspective without violating the second law, and living things in this view were thus *permitted* to exist, as it became popular to say, as long as they "paid their entropy debts." This worked for the classical statement of the second law per Clausius and Thomson, but in Boltzmann's view, such "debt payers" were still infinitely improbable. Living things, and *a fortiori* evolution as a planetary process as a whole, were still widely held, as Dennett's view shows, to be infinitely improbable states struggling against the laws of physics.

Returning to the balance equation of the second law, and making the implicit explicit for the first part of a two-part answer. Boltzmann's model works with certain simple near-equilibrium systems, such as the ideal gas in a box he developed it from, but the world is not a near-equilibrium system nor a gas in a box, and spontaneous ordering, rather than being "infinitely improbable" is ubiquitous and not just for living systems. In fact, studies of simple physical systems (without genes, brains, or other "makers") such as the well-known Bénard cell experiment show that beyond certain critical thresholds, Boltzmann's hypothesis fails, and order emerges not infinitely improbably but with a probability of one, that is, *every time, and as soon as it gets the chance* (for detailed discussions of the Bénard experiment, see Swenson, 1991a, 1991b, 1992; Swenson & Turvey, 1991). Indeed, this is just what the present biogeochemical record now suggests about the evolution of life on Earth in general. The remarkable work done in recent decades on the pre-Phanerozoic has provided a picture of evolution on Earth as a unitary planetary process where order emerges as soon as minimum magnitudes of critical thresholds are reached (e.g., the origin of life, not after some long lifeless period, but as soon as the Earth had cooled sufficiently after its formation so that its oceans would not evaporate, or the levels of order that arose when critical minimal levels of atmospheric oxygen were achieved, the Cambrian "explosion" being the most well-known case). What is the universal basis for this "urgency toward existence," as Leibniz (1697/1969, p. 487), put it? Why does order arise whenever it gets the chance? Why, in effect, is the world in the order production business?

The answer to the puzzle follows from two main facts. The first is discovered by returning to the balance equation of the second law and to the insights of Bertalanffy and Schrödinger, whose point, to restate, was that as long as an autocatakinetic system produces entropy fast enough to compensate for its development and maintenance away from equilibrium (its own internal entropy reduction), it is permitted to exist. Ordered flow, in other words, because it must pull in sufficient resources and dissipate them (minimize potentials) to satisfy the balance equation of the second law, must function to increase the rate of entropy production of the system plus environment—that is, whenever order emerges, entropy production must increase by a concomitant amount. There is an important but hidden implicit point in this that will now be stated explicitly: *To satisfy the balance equation of the second law, ordered flow must be more efficient at dissipating potentials than disordered* *flow, and it follows from this that the more order produced, the faster potentials are minimized*, and this brings us to the second and final piece of the puzzle.

The law of maximum entropy production—dissolving the postulates of incommensurability. The final piece to the puzzle that provides the nomological basis for spontaneous order production, and dissolves the postulates of incommensurability between psychology, biology, and physics, is the answer to a question that classical thermodynamics never asked. The classical statement of the second law says that entropy will be maximized, or potentials minimized, but it does not ask or answer the question of which out of available paths a system will take to accomplish this end. The answer to the question is that *the system will select the path or assembly of paths out of otherwise available paths that minimizes the potential or maximizes the entropy at the fastest rate given the constraints*. This is a statement of the *law of maximum entropy production*, the physical principle that provides the nomological basis, as we will see shortly, for why the world is in the order production business (Swenson, 1988, 1989c, 1991a, 1991b, 1992, 1996, in press-a, in press-c; Swenson & Turvey, 1991). Note that the law of maximum entropy production is in addition to the second law. The second law says only that entropy is maximized (or potentials are minimized), while the law of maximum entropy production recognizes the fact that the world acts to do so at the fastest rate given the constraints. Like the active nature of the second law, the law of maximum entropy production is intuitively easy to grasp and empirically easy to demonstrate.

Consider the case of the warm mountain cabin sitting in cold, snow-covered woods (Swenson & Turvey, 1991). The difference in temperature between the cabin and the woods constitutes a potential, and the cabin–woods system as a consequence will produce flows of energy as heat from the cabin to the woods so as to minimize the potential (e.g., by conduction through the walls, through the crack under the door, and so on). What the second law does not say is which out of available paths the system will select to do this. The law of maximum entropy production says the system will select the assembly of paths out of those available that minimizes the potential at the fastest rate given the constraints.

Suppose all doors and windows are shut, and heat is flowing to the outside primarily by conduction through the walls. Imagine now opening a window or a door which amounts to removing a constraint on the rate of dissipation. What we know intuitively, and can confirm by experiment, is that whenever a constraint is removed and a new path or drain is provided that increases the rate at which the potential is minimized, the system will seize the opportunity. In addition, because the opened window, for example, will not instantaneously drain all the potential, some will still be allocated to conduction through the walls. Each path will drain all that it can, the fastest (in this case the open window) procuring the greatest amount of potential with what is left going to the slower paths (in this case conduction through the walls). The point is that no matter what the specific conditions or the number of paths or drains, the system will automatically select the assembly of paths from among those otherwise available so as to get the system to the final state, to minimize or drain the potential, at the fastest rate given the constraints. This is the essence of the law of maximum entropy production. What does the law of maximum entropy production have to do with spontaneous ordering, with the fecundity principle, intentional ordering, or the filling of space–time dimensions?

Given what has already been discussed, the reader may have already leaped to the correct conclusion. **If** the world selects those dynamics that minimize potentials at the fastest rate given the constraints, **and** if ordered flow is more efficient at reducing potentials than disordered flow, **then** *the world can be expected to select or produce order whenever it gets the chance—the world is in the order-production business because ordered flow produces entropy faster than disordered flow*, and this means the world can be expected to produce as much order as it can, to expand space–time dimensions whenever it gets the chance. Autocatakinetic systems, in effect, are self-amplifying sinks that, by pulling potentials or resources into their own self-production, extend the space–time dimensions of the fields (system plus environment) from which they emerge and thereby increase the dissipative rate, and replicative ordering is the means for doing this, the dynamics that occurs, at the level we call living.

From extension to intension. The law of maximum entropy production, when coupled with the balance equation of the second law and the general principles of autocatakinetics, provides the nomological basis for putting the active epistemic ordering captured by the fecundity principle in its universal context and dissolving the postulates of incommensurability. The world can be expected to opportunistically produce as much order as it can, and the end-directed autocatakinetics of living things, that is epistemically determined and maintained with respect to nonlocal potentials discontinuously located in space–time provides the means to access otherwise inaccessible space–time dimensions. Elaborating the idea of epistemic determination by way of contrast, the end-directed behavior of rivers flowing down slopes, or heat flowing down temperature gradients, for example, are end-directed systems, but we need not invoke epistemic determination because the paths to their ends are intelligible in terms of local potentials and fundamental laws. When a bacterium moves up a concentration gradient, a bird flies above the Earth or opens its wings to effect a landing on a branch, a human drives a car, or moves some food from her plate to her mouth, this behavior, in contrast, can be seen to go in directions that are different to, and oftentimes opposite, those that follow causally from local physical potentials and laws. The autocatakinesis of living things is instead determined epistemically by meaning or information about discontinuously located nonlocal potentials, and it is by this means that the production of living order opens up access to otherwise inaccessible dimensions of space–time.

What is the principled basis for this epistemic determination, for intension (or "aboutness") in a physical world or environment that is otherwise taken to be exhaustively defined by extension?

The answer follows from Gibson's (1979/1986; Kugler, Turvey, Carello, & Shaw, 1985; Swenson, 1991b, in press-a; Swenson & Turvey, 1991; Turvey & Shaw, 1995) ecological conception of information, which itself can be shown to have a deep connection to general thermodynamic principles. In particular, living things are embedded in ambient energy flows (e.g., optical, mechanical, chemical) that are not used directly or dissipated as local potentials in the production of their autocatakinesis. As a consequence of first-law symmetry, lawful or invariant relations exist between the macroscopic properties of such ambient energy distributions and their sources with the further consequence that the former carry "information about" or can be used to specify the latter. A chemical gradient, for example, lawfully specifies the location of food for bacteria; diffusion fields of diffusing volatiles lawfully specify the location of resources or potentials for animals; and the dynamics of the optic flow field that envelopes a moving bird nomologically determines precisely when it must open its wings to effect a soft landing on a branch (Kim, Turvey, & Carello, 1993; Lee, 1980). Terrestrial evolution on this view can be understood as an epistemic process by which the world, through a process of trial and error, discovers ways to exploit the meaning inherent in the invariant or symmetry properties of ambient energy distributions to progressively learn ways to access new dimensions of dissipative space (space–time).

Dennett's idea of looking to algorithms as the source of all meaning in the world is the neo-Pythagorean version of the standard Cartesian idea that meaning or intension is not something that inheres in the physical world, but is a something that is created by a separate extra-physical part ("mind" for Descartes). Every logical and empirical problem already discussed or intimated with respect to Cartesianism disqualifies this view (see also Swenson, in press-a, in press-b). Meaning is not something that resides in isolated or contextless particles or pieces, whether ideal bits of program or not, but instead is found in the invariant properties that follow from natural law in the context of active, end-directed autocatakinetics. Empirically, it should be underscored, we know of no case of meaning or aboutness that exists outside this autocatakinetic–environment relation, and now, in addition, we have a nomological basis for understanding the nature of this epistemic ordering in its universal context (see e.g., Peck, 1996, in preparation; Swenson in press-a, in press-b, in press-c; Swenson & Turvey, 1991; Turvey & Shaw, 1995; for relevant discussion, see also Barham, 1996; Hoffmeyer, in press).

THE MAJOR CHALLENGES TO DARWINISM HAVE HARDLY BEEN CONTAINED

Finally, a few words must be said about Dennett's answers to the supposed critics of Darwinian theory. In his effort to build a pedigree and thus lend credence to his