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"Replaying Life's Tape": Simulations, metaphors, and historicity in Stephen Jay Gould's view of life

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ABSTRACT

In a famous thought experiment, Stephen Jay Gould asked whether, if one could somehow rewind the history of life back to its initial starting point, the same results would obtain when the "tape" was run forward again. This hypothetical experiment is generally understood as a metaphor supporting Gould's philosophy of evolutionary contingency, which he developed and promoted from the late 1980s until his death in 2002. However, there was a very literal, non-metaphorical inspiration for Gould's thought experiment: since the early 1970s, Gould, along with a group of other paleontologists, was actively engaged in attempts to model and reconstruct the history of life using computer simulations and database analysis. These simulation projects not only demonstrate the impact that computers had on data analysis in paleontology, but also shed light on the close relationship between models and empirical data in data-oriented science. In a sense, I will argue, the models developed by paleontologists through simulation and quantitative analysis of the empirical fossil record in the 1970s and beyond were literal attempts to "replay life's tape" by reconstructing the history of life as data.

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1. Introduction

In his 1989 book *Wonderful Life*, Stephen Jay Gould presented what has become a famous thought experiment in evolutionary biology. As he explained:

> I call this experiment "replaying life's tape." You press the rewind button and, making sure you thoroughly erase everything that actually happened, go back to any time and place in the past—say, to the seas of the Burgess Shale. Then let the tape run again and see if the repetition looks at all like the original. If each replay resembles life's actual pathway, then we must conclude that what really happened pretty much had to occur. But suppose that the experimental versions all yield sensible results strikingly different from the actual history of life? (48)

Gould's thought experiment was the basis for his developing theory that life is governed both by regular, law-abiding processes (natural selection, ecological dynamics, geological processes), as well as by "irreducible contingency"—the chance event (such as an asteroid falling out of the sky) that can alter the course of history in unpredictable ways. As developed during the last decade of his life, this argument became central to his broader evolutionary philosophy, as exemplified most fully in his magnum opus *The Structure of Evolutionary Theory* (Gould, 2002).

In this essay I will use Gould's thought experiment as a vehicle for examining the role of metaphors and historicity in models of evolutionary processes. In particular, I want to historicize the development of Gould's famous "tape of life" metaphor because, as I will argue, the metaphor developed directly out of a set of circumstances that illuminate its central meaning and application but which are not widely known outside of paleontology. Gould's metaphor, as I will show, did not originate as a response to his reading of the revised monographic literature on the mysterious Burgess shale fauna that featured so centrally in *Wonderful Life*. Rather, it was a conceit that he began to develop more than a decade earlier, in the context of a project he and several colleagues pursued to generate simulations of evolutionary phylogenies. This

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project, known as the "MBL model" and discussed in detail below, is the real source of inspiration for the "tape of life" metaphor, and the context of Gould's involvement in the simulation project and in subsequent efforts to model large-scale evolutionary patterns illuminates the development and significance of his views about the role of contingency—or of the balance between chance and determinism—in the history of life.

2. Data and Models in Paleobiology

Paleontologists have always been data collectors. As early as the 1830s and 1840s, paleontologists amassed large collections of data about the fossil record, and analyzed that data to generate representations of knowledge about the history of life (Sepkoski, 2012, 2013). These representations of data are, quite straightforwardly, "models of data," since they incorporate generalizing assumptions about the patterns and processes in the development of life over time. These models reflect the way scientists understand their data as telling us something about "the world"—in this case, about the history of life. These understandings are usually cast in terms of theories of evolutionary change: Gould's claim that the history of life has been shaped by "contingency" led him to propose a model of evolutionary diversification as a "cone of increasing diversity" (1989, 39–42).

Gould's position in 1989 and afterwards has been treated by some observers as a kind of philosophical presupposition or a "metaphysic" (Baron, 2009, 2011; Brysse, 2008). But a careful historian should ask where such a notion—or "metaphysic"—actually came from. One might expect that, as a paleontologist, Gould based his view of life on his experience examining patterns in the fossil record. This is certainly the way he presented it in *Wonderful Life*, where he used the reconstruction of the Burgess shale fauna by Harry Whittington and his students Simon Conway Morris and Derek Briggs to argue that:

> The reconstructed Burgess fauna, interpreted by the theme of replaying life's tape, offers powerful support for this different view of life: any replay of the tape would lead evolution down a pathway radically different from the road actually taken…. [This] represents no more nor less than the essence of history. Its name is contingency—and contingency is a thing unto itself, not the titration of determinism by randomness. (Gould, 1989, 51).

In *Wonderful Life*, the only basis Gould gave for his metaphor was a comment made by Conway Morris in a 1985 monograph on the Burgess invertebrate *Wiwaxia*, where Conway Morris wrote "if the clock was turned back so metazoan diversification was allowed to rerun across the Precambrian–Cambrian boundary, it seems possible that the successful body plans emerging from this initial burst of evolution may have included wiwaxiids rather than mollusks" (Conway Morris, 1985, 572; Gould, 1989, 238).

This and other comments in *Wonderful Life* gave the impression to some readers that Gould's thought experiment was inspired by his reading of Conway Morris—and for strategic purposes that may have been Gould's intention. One recent observer, Christian Baron, has even gone so far as to accuse Gould of "a masterful hijacking of Conway Morris's 'replaying the tape of life' metaphor" (Baron, 2011, 763). Unfortunately for this interpretation, the actual story is quite different. Baron gets it wrong because he fails to appreciate the significance of Gould's pre-1980s technical work. Gould did not "hijack" Conway Morris's metaphor—he could hardly have done so, given that Gould had been using it (in print, no less) almost a decade *before* Conway Morris's *Wiwaxia* monograph.

The story goes back to the very early 1970s, when a group of paleontologists—including Gould and his close colleagues David Raup and Thomas J. M. Schopf—set about to engineer a "paleobiological revolution" based on the introduction of "analytic" techniques to what they saw as a moribund, overly-descriptive discipline. In 1971, Schopf organized a symposium on "Models in Paleobiology," which sought to infuse paleontology with some of the exciting mathematical generalizations that had recently revolutionized theoretical ecology. As Schopf (1972, 11) described it in the introduction to the volume that followed the symposium, the purpose of the book was to place the "objects" of paleontology (i.e., fossils) "in the context of various generalizing notions … [to] achieve importance in proportion to the amount of evidence they provide for or against hypotheses." He explained that what "models have in common is the deliberate alteration of certain aspects of the real world in order to understand better certain other aspects" (11), and in particular he argued that "only by deductively making predictions from a set of data, and testing the consequences of the predictions, does one use a model" (12). In this introduction Schopf clearly expressed his preference for "equilibrium" or "steady-state" models, exemplified for example by Robert MacArthur and E. O. Wilson's model of island biogeography (MacArthur & Wilson, 1963, [1967] 2001).

The question that faced paleobiologists was how to put this into practice. The same year—1972—that the *Models in Paleobiology* volume was published, Schopf organized an informal meeting at the Marine Biological Laboratory at Woods Hole, Massachusetts. He invited Gould, Raup, and E. O. Wilson's student Dan Simberloff—all of whom had contributed papers to the *Models* symposium—to spend a weekend brainstorming about how patterns in fossil data could be translated into equilibrium models like MacArthur and Wilson's. For many years, Schopf, a University of Chicago paleontologist, spent his summers at Woods Hole, and in 1972 Gould was also planning to spend time there working on the draft of what would eventually be his first book, *Ontogeny and Phylogeny* (1977).[1] Schopf decided to take advantage of this coincidence by organizing a small brainstorming session, which he described in his invitation to Raup (dated March 5, 1972) as an opportunity "to get together for about three days to discuss the way in which theory can be more directly introduced into invertebrate paleontology." As he went on to explain, "of course, one can never 'program' good research, and in any event research is always done by individuals and not teams, yet the self-conscious attempt to introduce more theory into our mass of facts might be a very useful thing to do."[2] Simberloff was invited because, from the very start, Schopf envisioned that equilibrium island biogeography would have a prominent place in the brainstorming sessions. Schopf brought the best available data collections on fossils—the multi-volume *Treatise on Invertebrate Paleontology* and the 1967 compilation *The Fossil Record*—and essentially presented them to the participants with the challenge to analyze them for patterns.

This, unfortunately, turned out to be impossible. These sources were large, unwieldy print volumes, and the "data" they contained was presented in a variety of formats, none of which were easily amenable for mathematical analysis. Furthermore, the data itself was in poor shape, and Simberloff, who was brought in as the "data guru," recalls that it was far too fragmentary and incomplete to be analyzed in ecological terms. As Raup put it many years later (Sepkoski & Raup, 2009, 463), "We got nowhere. Dead zero." Data modeling is very difficult, it turns out, if one has poor data. But another kind of model was possible: a simulation model. Raup had experience with two kinds of simulation models. The first, which he

[1] Schopf to Gould, 3 February 1972, Box 5, Folder 14, Thomas J. M. Schopf Papers, SIA RU00742, Smithsonian Institution Archives, Washington, D. C.

[2] Schopf to Raup, 5 March 1972, Box 3, Folder 30, Thomas J. M. Schopf Papers, SIA RU00742, Smithsonian Institution Archives, Washington, D. C.