Scientific Progress as expressed by Tree Diagrams of Possible Histories

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1. Two Modern Views on Scientific Progress

Almost everyone agrees that there is *progress* in science: theories explain larger domains of reality with increasing precision, resulting in a constant appearance of new technological applications. But what is the nature of this progress?

Karl Popper (1963, pp. 231–3) assumes that, as time goes by, scientific theories increasingly approximate a true description of the world. In his convergent realism, in which scientific theories steadily increase their degree of verisimilitude, there is an unchanging reality which acts as an "attractor" for the evolution of science. The real natural world serves as a pre-fixed aim towards which science is directed.

In contrast to this view, Thomas Kuhn compares the progress of scientific ideas with the evolution of biological organisms.

> [The] resolution of revolutions is the selection by conflict within the scientific community of the fittest way to practice future science. [...] And the entire process may have occurred, as we now suppose biological evolution did, without benefit of a set goal, a permanent fixed scientific truth, of which each stage in the development of scientific knowledge is a better exemplar (Kuhn 1962, pp. 172–3).

Even if Kuhn's particular analogy with natural selection is considered unsatisfactory, there remains the interesting idea that there might be progress in science even if this does not happen in a prefixed direction. He returned to this notion in his "Reflections on my Critics" (Kuhn 1970, p. 264). A scientific revolution is the moment in which progress in science is highly sensitive to external influences, but in the long run the new paradigm is clearly superior to the former, according to usual criteria, such as precision of predictions and number of solved problems. So, in a sense, Kuhn is not a relativist in his notion of progress, since he conceives that the successor theory is superior in many aspects to the predecessor. On the other hand, he is close to relativism, since for him what makes a theory better than another is not its proximity to truth, as in Popper, but the fact that it is considered by the scientific community a better "tool for the practice of normal science". This relativism would apply to transitions *between* paradigms, but not *within* a paradigm, during the normal science activity of puzzle solution.

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2. Possible Histories of the Universe

One way of clarifying the concept of "progress without an attractor" (without a prefixed truth towards which science would converge), defended by Kuhn, is to consider *possible* histories of science (Pessoa 2001, 2005).

Let us suppose that on a certain date, say 1800, one hundred copies of the universe were created, and that the evolution of these different worlds were not deterministic, so that the history of each Earth would follow a different path. We would therefore have a hundred possible scenarios, one consisting of our actual history (which in fact occurred in our universe) and 99 "counterfactual" histories (i.e., possible histories that did not occur).

One might ask how long it would take, in the different worlds, for the molecular structure of DNA to be discovered, for example, and which paths would be followed. It is plausible to assume that the times would be different, and that there would be more than one basic path. Notice that we are assuming that the discovery of DNA would sooner or later take place in every one of the worlds, except maybe in a world destroyed by a world war. Now, although we feel safe to say that the *discovery* of DNA would happen in all copies made in 1800 (except for a cataclysm), the analogous question about what biological *theories* would have been developed in these universes is more complicated. Theories involve sets of explicit and implicit theses, the formulation of which depends on slight changes in language, in perspective, etc. Such theories would account for objective facts which are possibly the same in all universes, but the theories themselves could be different from world to world, to a greater or lesser extent.

What constrains should be imposed on the abstract generation of possible universes? How should one "build" possible worlds? First of all, we are not considering "logically possible" worlds, as is usually done in metaphysical and semantical discussions, but what might be called "causally possible" worlds. Consider a time t_0, such as this present instant, and consider all the future possibilities of the universe. A scientist may decide to pursue a line of investigation, or he might choose another. A certain lottery ticket might be drawn, or maybe another. An earthquake might happen in ten minutes, or in ten days. Assuming, for the sake of the argument, that the future is to a certain degree "open", i.e. that the precise evolution of the whole universe is not strictly deterministic, then it is meaningful to say that there are many different future "causally possible" scenarios of the world.

A possible history (which includes counterfactual histories as well as the actual one) is simply an evolution of the universe that, at some time t_0 *of the past* (of our actual world), was a future causally possible scenario. As a consequence of this definition, any counterfactual history must be indexed by a certain time t_0 (of our actual history), when it was a future possibility.

One "recipe" for constructing possible histories is to suppose that at the index time t_0 the universe is slightly "shaken" with a certain dispersion ΔS. For this purpose one could invoke a ?tychist demon? from the pantheon of demigods used in the philosophy of physics (the most famous of which are the Laplace and the Maxwell demons). To make matters simple, one could suppose that the universe evolves in a deterministic way, while it is not shaken. With this situation, we won?t have much problem with Leibniz?s principle of the identity of indiscernibles, since each copy of the universe produced by shaking is supposed to be slightly different from the other. We would thus have a moment of stochasticity when creating possible universes, which would be followed by a period of deterministic evolution.[1]

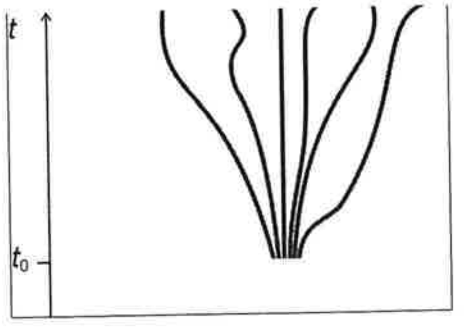


Figure 1: Representation of six possible histories of the universe, which would evolve deterministically in time t, starting from slightly different initial conditions.

Fig. 1 represents this situation qualitatively, for six possible histories of the universe. One might suppose, due to the notion of "sensibility to initial conditions" present in chaos theory, that the various universes which start out in slightly different states might end up diverging radically. If one also imposes the restriction of reversibility, two different possible histories would never evolve so as to converge to an exact same state.

If the universe were completely deterministic, it would follow that our future is not open, and strictly speaking there would be only one possible history of the universe and of science. Our analysis of counterfactual histories would therefore lose its ontological import, and would only express our ignorance concerning the details of the evolution of science. On the other hand, if the universe were truly indeterministic, then not only would possible histories have ontological import, but our "shaking procedure" (which would have the effect of a randomizing oracle in deterministic computations) could be applied at different moments of time. One consequence of this would be that a precise state of the universe could be attained by more than one possible histories.

3. Possible Histories of Science

In the previous section, we considered the evolution of the universe in microscopic detail, and considered a set of possible histories arising at a certain time t_0 by "shaking" the universe to a certain degree ΔS of dispersion. Small differences in microscopic detail in general would not lead to immediately noticeable differences at a macroscopic level.

As an illustration, consider the effects a very small earthquake might have in the lives of people living in a certain city. The daily routine would be changed a little, but there would be no immediate effects on the progress of science. But a boy who would become an important scientist might, because of the earthquake, have arrived late in science class, and received a reprimand from the teacher, and this could ultimately influence his decision later in life to become a musician instead of a scientist. If the boy's name were Albert Einstein, what consequences would that have for the development of science?

In this example, the effects of the earthquake would in most cases not affect Einstein's career choice, but in a smaller number of possible worlds it might. Fig. 2 compares the evolution of six possible universes with the "coarse grained" evolution of science in these six worlds (the latter "supervenes" on the former). In most of the worlds considered, Einstein might have arrived at the theory of general relativity, but in the world in which he chose to become a musician, he would not. What would be the consequences for physics of this scenario in which Einstein becomes a violinist?

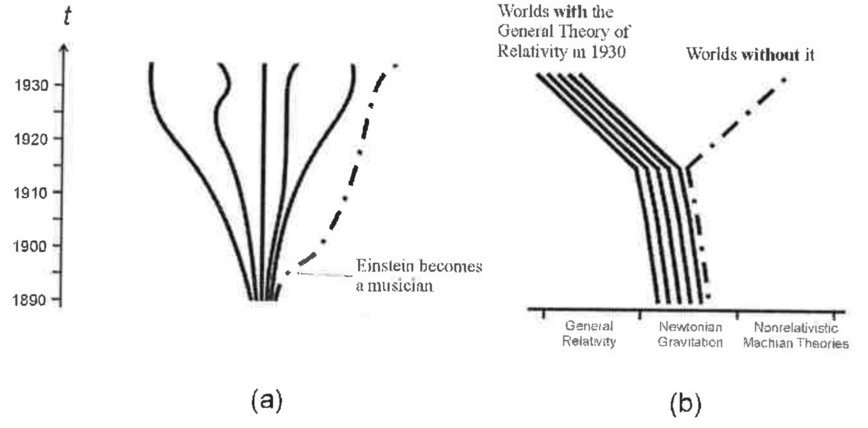


Figure 2: (a) Six possible universes generated in 1890. It is assumed that Einstein becomes a musician in on of them. (b) Possible histories of science, that supervene on the possible universes. In five of these, Newtonian theory of gravitation is replaced by general relativity, but in the sixth, a nonrelativistic Machian theory supersedes Newtonian theory.

It is plausible to suppose that the seminal ideas of Einstein's three great papers of 1905 would have appeared within a few years, possibly by other paths. The principles of the special theory of relativity were being studied by Lorentz and Poincaré; the theory of Brownian motion could have arisen with Smoluchowski; and the realization that light has a granular aspect had already been suggested by J. J. Thomson in 1904, and the concept of the quantum of light could have probably arisen before 1922, which is roughly the date that Einstein's theory was actually accepted.

However, there is a certain consensus among cosmologists that the *general* theory of relativity, concluded in 1916, would not have appeared so quickly in a world in which Einstein had not become a physicist. It is plausible to speculate that, in this case, it would take around half a century for general relativity to be formulated. What would have happened in this period of time? Would Newtonian theory of gravity remain the best available theory? Probably not: at the turn from the 19th to the 20th centuries, many physicists were exploring nonrelativistic "Machian theories" (see Barbour & Pfister 1995), which introduces a velocity-dependent gravitational potential and implements Mach's idea that only relative distances should be used in mechanics (no absolute space). Such theories have a larger explanatory power than classical theory, and probably would have been used to account for different effects, such as the advance of Mercury's perihelion, until the appearance of the general theory of relativity or another equivalent theory.

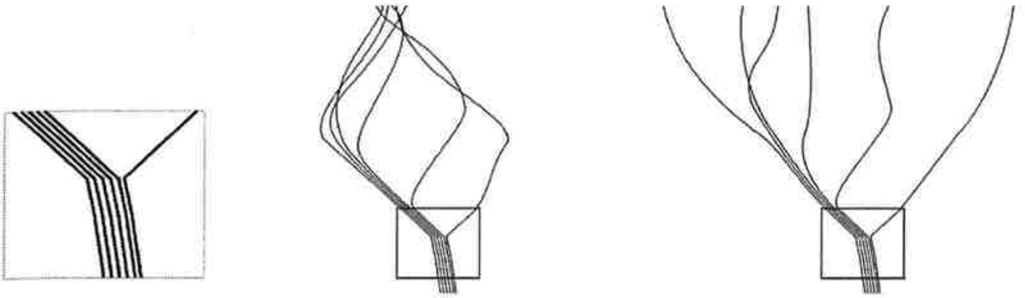
Counterfactual conjectures, such as the one just given, are seen with suspicion by historians of science, but they are just another way of stating causal claims. In the present example, one could say that the appearance of general relativity in 1916 had, as a necessary condition, Einstein's genius and his profound understanding of the principle of relativity.

4. Conceptions of Progress expressed in Trees of Possible Histories

In the previous section, we described a bifurcation of possible histories of science, obtained after "shaking" the universe at a certain time. Possible histories of science would initially follow the same path, but then most of the worlds would diverge, one after the other, from the main branch. In such diagrams, the horizontal axis represents qualitatively different theories or different formulations of theories (see further discussion in section 5).

The notion of a bifurcation of possible histories (Fig. 3a) is consistent with both the views of Popper and Kuhn, in spite of the differences in their overall view of scientific progress. The distinction between these views is expressed in a direct way with tree diagrams of the possible evolution of science,

The "objectivist" view is characterized by the claim that there is a convergence of scientific theories in most of the possible histories of science (Fig. 3b). This includes Popper's realist conception, but it is a broader view than realism, as will be discussed in section 8. Kuhn's conception of evolution as the selection of the fittest theory is represented, in Fig. 3c, as an "open" tree of possible histories of science. As stressed by Kuhn (1970, p. 264), there is progress if one considers different points of a *same* branch, but in principle science could follow diverging paths in different possible worlds.



(a) (b) (c)

Figure 3: Trees of possible histories of science. (a) The pattern of bifurcation of Fig. 2 is consistent with different views on the progress of science. (b) Objectivist views of scientific progress, such as Popper's, would claim that possible histories of science end up converging. (c) Kuhn's view is that the possible histories diverge, lacking an "attractor".

With such tree diagrams, one may express different views on the progress of science. Fig. 4, for example, would be a situation in which the initial bifurcation places the scientific field in a definitive paradigm. An illustration of this possibility could be a choice between an atomistic view of the physical world or an oscillatory (wave-motion) view. Needham (1962, pp. 3–14) has claimed that within the ancient Taoist worldview in China the oscillatory paradigm was dominant, and not the atomistic one, prevalent in Europe. If we assume that modern science could have arisen within the oscillatory paradigm (this is just an illustration, I wouldn't want to commit myself to this hypothesis), we could imagine that DNA could be conceived not as a bunch of atoms, but as a set of resonant oscillations. Fig. 4 represents the view that there would be convergence of possible histories only within each paradigm.

Figure 4: Alternative hybrid model for the progress of science, with convergence of possible histories only within each general paradigm.

5. Distance between Scientific Theories

In the trees of possible histories of science (Fig. 3), the horizontal axes represent qualitatively the *distance between theories.* If at a certain time two possible worlds arrive at very different theories (such as a nonrelativist Machian theory and general relativity), their branches will be represented far apart; but if the theories in the two worlds are similar, then their branches will be put close together. But how should one measure quantitatively the distance between theories?

One suggestion would be to compare the *empirical adequacy* of the theories, i.e. the extension and precision with which each theory predicts the experimental data. But that is not what we want to capture, since different theories, built in different ways, could end up accounting for the same set of data. A better solution would be to compare the theses that compose each theory. If they share many theses, then they would be close, if not, then they would be distant. If the theories are axiomatized, then one might compare their postulates. If they are analyzed according to Lakatos' (1979) methodology of scientific research programmes, then one could compare the theses in each hard core and protection belt, giving greater weight to the first. However, such a comparison might be difficult for two theories that are considered incommensurable. The problem of comparing the distance between theories is difficult and interesting, and will be left open.

The semantical approach to scientific theories chooses to define a "theory" as the associated class of models, so that a same theory may have many different formulations. Thus, in the language of the semantical conception, our concern is to define not only the distance between different theories but also the distance between different *formulations of theories.*

One should also remark that science doesn't consist only of theories, but also of instruments, experiments, data, laws, explanations, and any other class of advances. Each of these aspects is important for science, and for each of them one could ask whether the different possible histories of science are more or less similar.

6. Possible Paths

The history of science only happens once on Earth, so we have no direct access to counterfactual histories. However, within our actual history, scientists work in competition, following similar or distinct *paths* in the search of laws, in the construction of instruments, or the attainment of any other advance. Darwin and Wallace followed similar paths towards the independent discovery of the principle of natural selection, Heisenberg and Schrödinger followed dissimilar paths to reach quantum mechanics.

Paths towards discovery may happen in a complete way in independent discoveries, or they may be aborted by a certain research group when another group makes the discovery. Hindsight allows the historian to conjecture about possible paths that were initiated but remained incomplete in the past, or even about possible paths that were not even initiated.

Each actual or counterfactual path can be considered part of a possible history of science. Thus, the study of *actual independent paths* is a valuable step towards conjecturing possible histories, besides being an interesting topic of study in itself.

7. Degree of Dispersion of Possible Histories or of Paths

When one postulates possible paths or possible histories of science, how wide should the range of possibilities be taken? For example, if one starts with the actual situation of biology in 1830, one could imagine possibilities that are closer to factual history, or possibilities that are farther removed from actuality (such as the situation in which Mendelian genetics would be accepted *before* the theory of natural selection). This distinction reflects what might be called the "degree of dispersion" or "degree of fluctuation" ΔH of possible histories of science. Such a concept would not apply directly to a single possible history (which, by itself, has null dispersion), but to a set of them, and should be connected to the dispersion ΔS of possible universes.

On the other hand, one might consider the degree of dispersion of paths ΔP within a history of science. In our actual history, such a dispersion might depend on political divisions, which tend to isolate research communities (such as the division between science in the Soviet Union and in the West), and on other social and institutional factors. If well defined, the dispersion of paths ΔP may be measurable in actual history.

8. Objectivist Theories

The analysis of scientific progress terms of possible histories has led to the definition of an *objectivist* point of view, that conceives of possible histories of science as converging in the future, in opposition to the *relativist* position of Kuhn, which would admit an open tree of possible histories. Objective views might be formulated as stating that there is an "attractor" for the progress of science, but there are different possibilities for such an attractor.

Scientific realism argues that such an attractor is constituted by the existence of an unchanging reality which science attempts to represent. Different varieties of realism disagree on the exact relation between theory and reality. Strong forms of realism conceive of science as mirroring nature in a faithful way, while weaker forms postulate only a one to one (or many to one) relation between reality and theory (see example in Pessoa 2006, pp. 177–9).

Objectivism is also consistent with the notion that science converges not because of the unchanging nature of reality, but because of the way that knowledge is constructed. This might include Kant's objective constructivism and Poincaré's conventionalism, in which scientists choose the simplest of conventions. An analogy with this mode of constructivism may be drawn with the notion of convergent evolution in biology, a tendency for living beings to occupy specific ecological niches (Pessoa 2006, pp. 175–7).

We hope to have shown that the general consideration of possible histories of science can help to clarify different points of view in the philosophy of science.

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Notas

[1] The problem of whether the universe is deterministic or not is an open question. In general, given an indeterministic model of a physical system, it is always possible to construct an equivalent deterministic model, introducing hidden parameters (this is also valid for quantum mechanics, as David Bohm showed in 1952). This equivalence allows that systems that are usually treated as stochastic be reformulated in a deterministic way, if this brings any advantage for the analysis or any satisfaction to our intuition. This is what we have chosen to do here.

Coleção Rumos da Epistemologia

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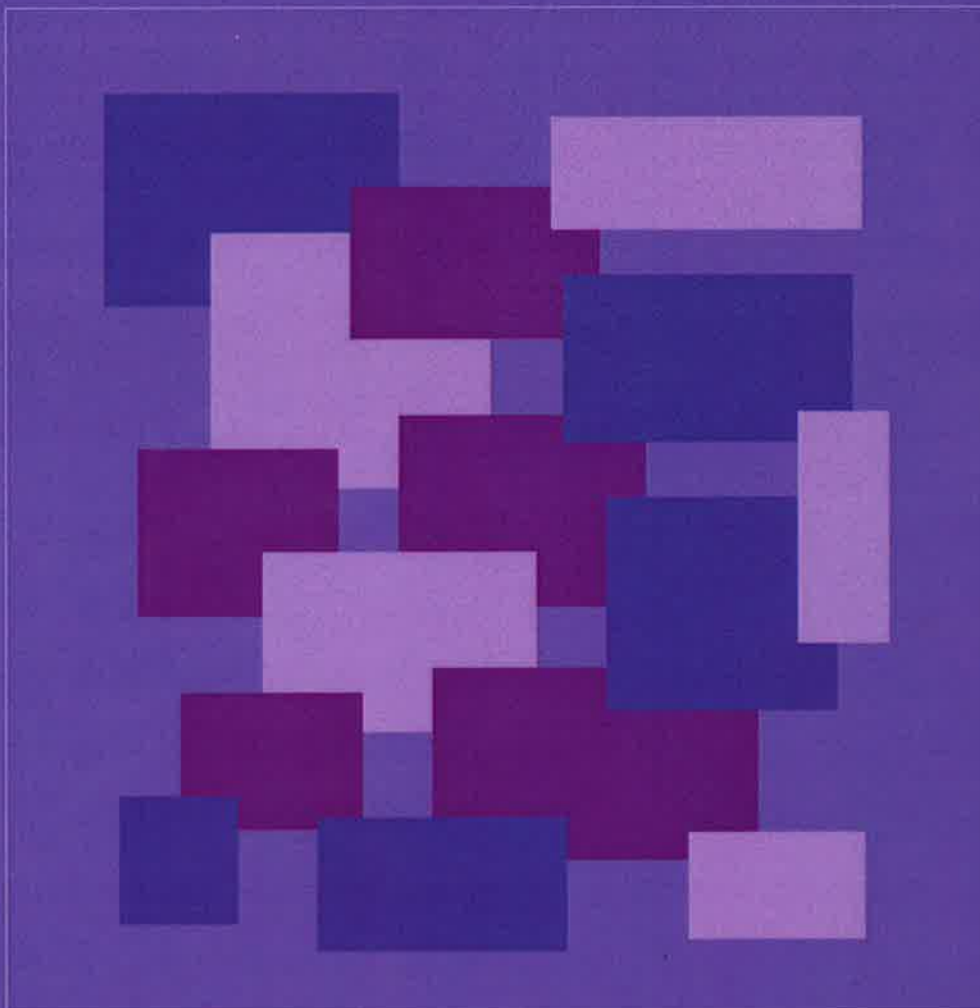

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