

Holding the hand of history. Mach on the history of science, the analysis of sensations, and the economy of thought¹

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Introduction

Ernst Mach's historical attitude in analyzing the epistemological structure of natural sciences can hardly be overlooked by anyone who approaches his work. Examples can easily be traced throughout his activity. Many of his contributions to epistemology are even explicitly presented as, or entirely devoted to, historical reconstructions of some definite concept or discipline — e.g., *Die Geschichte und die Wurzel des Satzes von der Erhaltung der Arbeit* (1872), *Die Mechanik in ihrer Entwicklung historisch-kritisch dargestellt* (1883), *Die Principien der Wärmelehre. Historisch-kritisch entwickelt* (1896), *Die Prinzipien der Physikalischen Optik. Historisch und erkenntnispsychologisch entwickelt* (1921), to quote the most representative in that connection.²

Although each of these works deals with different subjects (apart from some inevitable overlapping or repetition), all of them share a similar concept that emerges from the label *historisch-kritisch*, frequently used in their titles or prefaces (this is the case, e.g., with the 1909 preface to Mach 1872/1911, which qualifies such work as “the first attempt to apply my *erkenntniskritischen* point of view” (p. iii)). In their

¹ I am grateful to Pietro Gori and John Preston for their stimulating criticisms and observations, as well as for having read an early draft of this chapter and having shared with me their comments.

² For the English translations, see respectively Mach (1872/1911, 1883/1960, 1896/1986, 1921/1926). Very pragmatically, I do not hesitate to quote from these translations, for they are well in use in the Mach studies. Where words are particularly important, or where I do not find the translation entirely convincing, I compare the passages with the original text and refer the German phrases (although without giving the original pagination, for reasons of brevity). For this purpose I mainly used the “Ernst-Mach-Studienausgabe” (Berlin: Xenomoi, 2012-2016), collecting so far five volumes, and the original second edition of *Die Geschichte und die Wurzel...* (Leipzig: Barth, 1909).

recent introduction to Mach's *Prinzipien der Wärmelehre*, Michael Heidelberger and Wolfgang Reiter have proposed the following characterization of the historical-critical approach:

Broadly understood, “historical-critical” means to take into consideration the history of a certain discipline while assessing it. However, through that idea Mach expresses much more than this: the historical development of a science provides a reservoir of ‘modes of thinking’ for human beings in dealing with experience. These can be resumed at any time and become effective again, even in our present sciences ... The resulting critical assessment lets the current development of a certain science appear in an essentially contingent light, and thus it prevents from dogmatic solidification (Mach 2016, p. XIII).

As with many other traits of Mach's epistemology, this strong commitment to history is a “many-footed beast”.³ Erwin Hiebert (1970) pointed to five “dominant lessons” regarding his approach to the history of science that, I think, are commonly assumed by Mach scholarship: 1) scientific “concepts, laws, and theories are in constant flux”; 2) everything in science is subject to a perennial “revision and reformulation” — hence there is no reason to consider our recent views as absolutely correct, although they are more adequate to experience, under certain respects, than previous conceptions; 3) what at first appears as a necessary development and a result of alleged *a priori* mechanisms, reveals itself, after closer examination, as historically contingent

³ I borrow this expression from a paper by Erik Banks (2004, p. 24), who applied it to the principle of economy of thought. Erik devoted much of his research to exploring Mach's philosophy in a particular turn — neutral monism. He was one of the best and most generous researchers I have ever known; I learned very much from his studies and from our dialogues, which I regret were too few. This paper is dedicated to his memory as a kind of word of gratitude that I would have liked to say personally to him.

and dependent on cultural and even individual inclinations; 4) past achievements are not past once and for all; rather, our “modern” views are the result of a tradition inherited from that past, which is as ancient as the very first “instinctual” beginnings of *Homo sapiens*; 5) since there is no sharp boundary between science and “instinctual knowledge”, the products of science not only reflect a historical-cultural contingency but also a biological contingency: they demonstrate human cognitive capacities as they appear throughout the history of culture, they “disclose the mode of cognitive organization of experience”.⁴

Hiebert's list, complete or not, represented a noticeable advancement in the understanding of, as emphasized by the title of his paper, “Mach's philosophical use of history of science”. Two important features of Mach's conception, however, remain out of this catalogue: his theory of neutral elements (on which are based both psychical and physical events) and his principle of thought economy, of which Hiebert only says that it may “help us to understand how the history of science was pressed into the service of the philosophy of science” (ibid., p. 201)

The present chapter aims to study what kind of relation these two recurring themes of Mach's conception have to his historical approach. It takes its cue from a question originally raised by Ronald Giere's influential review of the fifth volume of *Minnesota Studies in the Philosophy of Science*, entitled *Historical and philosophical perspectives of science*, which included Hiebert's article along with other papers on the relation between history and philosophy of science (Giere 1973). Giere took for

⁴ For my “Hiebert's list” I took inspiration from the original one (Hiebert 1970, 188-189, 197-198), which I tried to re-arrange logically and to integrate with other parts of his argument: “The dominant lessons that shine through Mach's deliberations are these: Science has an incredibly rich history. Its ideas are alive. Its concepts, laws, and theories are in constant flux. They are perennially under revision and reformulation. The conceptual products of science, always incomplete, take on a form at any particular time which reflects the historical circumstances and the focus of attention of the particular investigator — now physicist, now physiologist, now psychologist. Strictly speaking, scientific constructs therefore disclose the mode of cognitive organization of experience ... The history of science, Mach believed, demonstrates that there are no sharp boundary lines separating the scientific from the nonscientific or prescientific experience of man”.

granted that Mach provides a significant case study in this connection; he argued, however, that Hiebert did not clarify how “Mach’s philosophical views, e.g. on the epistemological role of sensations or the economy of thought, have any ‘logical’ or ‘conceptual’ relations to either his physical or historical investigations”; finally, he wondered, if that was the case, “what precisely these relations might be” p. 283). As will become clear in the following sections, I think Giere was wrong about what he called, somewhat inexactly, “the epistemological role of sensations”; still, it seems to me that he captured a real gap in Mach studies which goes well beyond Hiebert’s interpretation. And filling this gap may explain the role of history — not only its “philosophical use”, as if it were a tool that can be employed or put aside — in Mach’s thought.

Mach on the utility of history for life

In 1909 Mach republished his oldest historical-critical investigation, *Die Geschichte und die Wurzel des Satzes von der Erhaltung der Arbeit*, originally a lecture held in Prague in November 1871 and issued some months later, in 1872, as a sixty-page offprint. As it transpires from his correspondence as well as from the new preface and additions, the reissue was part of a strategy of self-defense from the fierce attack that Max Planck launched against Machian epistemology during his 1908 Leyden lecture, *Die Einheit des physikalischen Weltbildes* (see Guzzardi 2002, pp. 419-420; Mach 2005, pp. 28-31). So Mach (1872/1911, p. 9) begins the new preface by remarking that this essay was his “first attempt to give an adequate exposition of [his own] epistemological standpoint [*erkenntnistheoretischen Standpunktes*]”, based on the principle of economy — which was, in turn, the object of Planck’s most bitter criticism.⁵

⁵ Planck’s criticism came to a climax when he stated that “should Mach’s principle of economy actually be shoved into the center of epistemology, it might well disturb the thought processes of leading minds, lame the flight of their imagination, and by such means interfere with the progress of

In the 1872 original essay such an epistemological point of view was expressed in historical fashion, and the introduction explains why. It opens with an epigram from Gotthold Ephraim Lessing, employed to illustrate allusively how people tend to take as self-evident things that are, in truth, historical events and have happened for some reason, or resulted from some conditions, that one can describe and reconstruct *a posteriori*.⁶ A similar tension between illusory obviousness and the complexity of the real, according to Mach (1872/1911, p. 16), occurs when, in school years, “propositions which have often cost several thousand years’ labour of thought are represented to us as self-evident”. There is, however, one antidote to such a deceptive way of learning: “historical studies”. Otherwise, the price for the lack of a sense of history can be high, for it promotes a reifying, metaphysical attitude, as far as “we are accustomed to call concepts metaphysical, if we have forgotten how we reached them”. Contrariwise, “one can never lose one’s footing, or come into collision with facts, if one always keeps in view the path by which one has come” (Mach 1872/1911, p. 17).⁷

In accordance with this view, Mach (1872/1911, pp. 16-17) points out that the essay contains “considerations which, if I except my reading of Kant and Herbart, ... have arisen quite independently of the influence of others [and] are based upon some historical studies”. They pertain to “some facts belonging both to natural science and

science in disastrous ways” (Planck 1909, pp. 36-37; for the English translation, see Blackmore 1992, pp. 131-132). Mach’s correspondence with friends leaves no doubt that he was profoundly touched by this kind of acrimony (Wolters 1987, pp. 19, 32-33).

⁶ Lessing’s original epigram (“Hänschen Schlau”, from his *Sinngedichte*, collected in Lessing 1970, p. 23) reads as follows: “*Es ist doch sonderbar bestellt, / Sprach Hänschen Schlau zu Vetter Fritzen, / Dass nur die Reichen in der Welt / Das meiste Geld besitzen.*” (“‘Sure, it is remarkably arranged’ / Told Little Smart Hans to Cousin Fritz / ‘That only to the rich in the world / most of the wealth belongs’”).

⁷ By the way, Mach also complains that the unhistorical attitude of his colleagues promoted a campaign against him: “The reason why, in discussion of these thoughts with able colleagues of mine, I could not, as a rule, come to agreement, and why my colleagues always tended to seek the ground of such ‘strange’ [*sonderbar*” in the German text: note that he is using an expression employed by Lessing in the above-quoted epigram] views in some confusion of mine, was, without doubt, that historical studies are not so generally cultivated as they should be” (Mach 1872/1911, p. 16).

to history” and may also serve to instantiate “the value of the historical method in teaching” — which is characterized as follows:

If from history one learned nothing else than the variability of views, it would be invaluable. Of science, more than anything else, Heraclitus's words are true: “One cannot go up the same stream twice”. Attempts to fix the fair moment by means of textbooks have always failed. Let us, then, early get used to the fact that science is unfinished, variable. Whoever knows only one view or one form of a view does not believe that another has ever stood in its place, or that another will ever succeed it; he neither doubts nor tests... We believe, rather, that it can do us no harm to know the point of view of another eminent nation, so that we can, on occasion, put ourselves in a different position from that in which we have been brought up (Mach 1872/1911, pp. 17-18).

The introduction closes, after some lines, with Mach's famous motto: “Let us not let go the guiding hand of history. History has made all; history can alter all”.

This picture of history as an ever-changing stream with an unpredictable course is well in line with the first three lessons in Hiebert's list. With the image of Heraclitus's river, Mach defends the idea that scientific notions and practices are in constant flux (Hiebert's lesson 1); by saying that one cannot fix them once and for all in textbooks, he indirectly argues for our scientific notions being subject to “revisions and reformulations” (Hiebert's lesson 2); Lessing's epigram and the related complaint about those who are satisfied with their own view and know nothing of others, warn against dogmatism, intimating that things that appear obvious and necessary are, in truth, the result of a contingent development (Hiebert's lesson 3). As to lessons 4 and 5, that will build the pillars of Mach's naturalized epistemology, they will be explored in detail in later works, from *The Science of Mechanics* to the *Principle of the Theory of*

Heat and Knowledge and Error; but their seeds are already appreciable in the 1872 essay on the principle of the conservation of work. In particular, here Mach traces the idea that it is impossible to create work out of nothing, or “the principle of excluded *perpetuum mobile*”, back to Simon Stevin, Galileo Galilei, Christiaan Huygens, etc., on the grounds that it is an incarnation of the principle of causality. This, in turn, is a sort of regulative, pre-mechanical principle that is applied everywhere the attempt to investigate nature is made (Guzzardi 2014).

I think, however, that the most important aspect of Mach's paean to history is that it helps understand — adapting Giere's phrase — the conceptual relation of his philosophical views on sensations to the historical investigations he carried out. This is the argument of the next section.

Was ist Metaphysik? The history of science and *The Analysis of Sensations*

The Analysis of Sensations (Mach 1886/1959) is perhaps the less historical of Mach's epistemological books. Examples from the history of science appear only sparingly therein and, when taken into consideration, they play but a marginal role. The book famously opens with a chapter titled “Antimetaphysical premises” (“*Antimetaphysische Vorbemerkungen*”) where Mach presents his ontology made out of neutral elements, in themselves neither physical nor psychical, which constitute, however, both the physical and the psychical. This conception would sometimes be regarded as a kind of phenomenalism, sometimes be called “neutral monism”, associating Mach with thinkers like William James and Bertrand Russell.⁸

In contrast with a widespread view, textual evidences show that, in *The Analysis of Sensations*, Mach does not give a literal, crystal-clear definition of what should be

⁸ The most important supporter of the neutral-monist interpretation of Mach in recent times is Banks (2003; 2014). For an overview of the neutral monist conception, see Stubenberg (2018). For a compared appraisal of the two readings, see Preston (this volume).

understood as *metaphysics*, *metaphysical*, and related expressions. Most of the time Mach uses these terms somewhat generically, in a manner that seems to imply something that is not grounded in experience. For example, Mach (1886/1959, p. 61) sees the difference between his conception and Gustav Theodor Fechner's psychophysical parallelism in the fact that his own "has by no means a metaphysical substrate [*Untergrund*] but corresponds only to the generalized expression of experiences" (note that in the current English translation *Untergrund* is rendered as "background"). A further example is Mach's (1886/1959, p. 171) characterization of will, which should not be understood as "any special psychical or metaphysical agent" but must be "explained by means of the physical forces of the organism alone".

A more general formulation can be found in the 1902 preface to the fourth edition of *The Analysis of Sensations*: the idea that "science ought to be confined to the compendious representation of the actual [*Tatsächlichen*], consequently leads to the elimination of all superfluous assumptions which cannot be controlled by experience, and, above all, of all assumptions that are *metaphysical* (in Kant's sense)" (Mach 1886/1959, p. xii). The reference to Kant is, to a certain extent, clarifying. Autobiographical fragments partly contained in Mach's works and partly in unpublished notes show that Kant, particularly through the *Prolegomena to Any Future Metaphysics*, had a strong influence on the young philosopher-scientist (Blackmore 1972, pp. 10-11, 289; Banks 2003, pp. 24-25). In the *Prolegomena*, recalled in a footnote to *The Analysis of Sensations* (Mach 1886/1959, p. 30), Mach could read that the sources of metaphysical cognition "cannot be empirical. The principles of such cognition ... must therefore never be taken from experience" (Kant 2004, p. 15). There seems to be no reason why, in his mature years, Mach should reject the characterization he learned about in his earliest philosophical excursions (Blackmore 1972, p. 33) — but of course, he attached to it a pejorative connotation that was alien to Kant.

As is well known, the Vienna Circle and its epigones, on whom greatly depends

the received view of Mach's epistemology, stuck to assertions of this kind for their preferred image of him as the champion of an "antimetaphysical" phenomenalism, having sense-data (sensations) as its proper ontology. After all, this seemed quite consistent with Mach's aversion to non-observable entities like Isaac Newton's absolute space and time, as well as atoms and forces, which he wished to be eventually eliminated from science. This phenomenalist-sensualist interpretation of Mach's epistemology may underly Giere's reference to "the epistemological role of sensations" and its relation, if any, with his "physical ... investigations". In any case, a harsh criticism of this image of Mach, that has more in common with the search for a noble "legendary father" than with an objective historical reconstruction, can already be found in Paul Feyerabend (1970; 1984). (Of course, this does not exhaust all the possibilities of a *phenomenalist* reading of Mach: see Preston, this volume).

More recently, the legend has been challenged in many ways. Even if the influence of Mach on the adherents of the Viennese movement is beyond question (Stadler 1997; 2007; this volume), significant differences must be taken into account as well. Some scholars have emphasized that logical positivists were not committed to an updated version of empiricism but rather aimed to develop a common formal structure for scientific theories based on the analysis of language (Richardson 1997; Friedman 1999; Mormann 2007; Banks 2013). Others have highlighted that Mach was particularly committed to his elements being neutral, i.e. neither physical nor psychical in themselves. Feyerabend (1984, pp. 10-11) argued that Mach's theory of the elements was "not a necessary boundary condition of research" but a particular *theory*, formally analogous with the atomic hypothesis; moreover, that "elements are sensations 'but only insofar' as we consider their dependence on a particular complex of elements, the human body; 'they are at the same time physical objects, namely insofar as we consider other fundamental dependencies'". And according to Banks (2003, 46), the theory of the elements can even be considered as part of "a strategy for

the future development of science”; as he wrote elsewhere, it was — in a strong, philosophically traditional sense — an example of a “good metaphysics, even if Mach would have rejected the term”, which stands at odds with the Vienna Circle’s ideas (Banks 2013, pp. 58-64; see also Banks 2014 and 2018).

To the criticisms only briefly sketched here, may I add that the neopositivists overlooked one essential feature of Mach’s antimetaphysical discourse, which is not explicitly included in *The Analysis of Sensations* but can be understood in light of the above-quoted introduction to the essay on the principle of the conservation of work. As I mentioned, here metaphysical concepts are described as those that have gone through an unconscious process of intellectual solidification, that hinders us from tracing them back to their origin; perhaps they are available for use or we even continue to make use of them as obvious, but “we have forgotten how we reached them” (Mach 1872/1911, p. 17). On the other hand, history can preserve from this kind of dogmatic solidification of concepts, for one can remain “in view of the path by which one has come” and this prevents one from “losing one’s footing, or coming into collision with facts”. In other words, the history of science can have, and in fact has in the 1872 essay on the principle of the conservation of work, an antimetaphysical function.

Now, what Mach calls analysis in *The Analysis of Sensations* — that is the resolution of complex concepts like matter, bodies, the ego, etc., into their composite elements — has an analogous function, even if it proceeds via very different methods. Still, it possesses the same virtue of reminding us that the concepts we use emerge from certain physical-psychological relations among more elementary materials, which are subject, in turn, to further analysis. It is not my aim to proceed to a more or less complete exposition of Mach’s conception in this regard, nor do I intend to assess its benefits and flaws. I just want to emphasize that there is a double parallel here with the idea of history Mach advanced in the essay on the principle of the conservation of work. On the one hand, like the “historical studies” in that context, the kind of analysis undertaken

in *The Analysis of Sensations* reveals a sort of heraclitean flux underlying apparently permanent compounds — concepts like matter, the body, the ego, etc. On the other hand, it also helps to explain (and to suggest) where they may find their legitimate use and how to polish from them possible metaphysical residues.

Let us take as an example Mach's famous analysis of the *Ich*, the ego. For the common understanding, this is something unchangeable. However, its apparent stability dissolves as soon as, after closer inspection, the ego manifests itself as a “*relatively* permanent ... complex of memories, moods, and feelings, joined to a particular body — the human body” (Mach 1886/1959, p. 3). The elements that form the ego, Mach continues, are transient events that do not repeat themselves identically but only gradually change, and this ensures our ability to recognize ourselves, as well as others, as time passes and leaves its marks on us. Of course, there is nothing wrong with considering the ego such a “*practical* unity, put together for purposes of provisional, orientating consideration”; we have reason to act accordingly in our everyday life, since “the supposed unities ‘body’ and ‘ego’ are only makeshifts, designed for *provisional* orientation and for definite *practical* ends” (Mach 1886/1959, p. 28). There is nothing metaphysical here, insofar as we can explain this tendency as a development of our natural needs (in modern terms, as far as we can explain this by means of a naturalized epistemological approach). What is metaphysical is rather to consider the ego as an unanalyzed concept we can *obviously* use for research purposes — what is metaphysical is the solidified version of the ego in philosophy and psychology (in particular, according to Mach, in Kant's philosophy: see Banks 2013, p. 65), i.e. the belief that the ego really has an unchanging existence.

With this, I am not arguing that the historical and the analytical approaches are really the same thing or that one approach is (logically, conceptually, historically, or in whatever manner) dependent on another — for example, that Mach's historical-critical mode of examining the emergence and development of scientific notions and practices

derives from his analytical attitude in perceptual psychology, or vice versa. Following a hint in the above-mentioned footnote of *The Analysis of Sensations*,⁹ I rather think that the two approaches originated independently, but possibly from the same need, in the early stages of Mach's career; then they started to interact and reinforce one another, probably already in the early 1860s, as he was working on the *Compendium der Physik für Mediciner* (1863) and while dealing with the *Vorträge über Psychophysik*.¹⁰

In other words, for Mach the historical-critical point of view and the analysis developed in his physiological-psychological studies on sensations were two barrels of the same antimetaphysical gun.

Mach on the economy of thought and the history of science

Let us return to Hiebert's assessment of Mach's epistemology. The other important point mentioned by him (Hiebert 1970, p. 201), but — according to Giere (1973, p. 183) — not adequately examined, is the relation, if any, of Mach's doctrine

⁹ Footnote 1 of p. 30 (in the current English version) gives a well-known and often-quoted autobiographical sketch of Mach's early interest for (and dismissal of) Kantian philosophy, which is brought into connection with his reflections on "the world with my ego [appearing ...] as one coherent mass of sensations, only more strongly coherent in the ego". This memory also includes a frequently overlooked passage: "Only by alternate studies in physics and in the physiology of the senses, and by historical-physical investigations (since about 1863), and after having endeavored in vain to settle the conflict by a physico-psychological monadology (in my lectures on psychophysics ...), have I attained to any considerable stability in my views" (Mach 1886/1959, p. 30). On this, see also Banks (2003, esp. pp. 23-26), who dates the end of the "intense intellectual 'struggle' during the 1860s, that led Mach to his theory of elements", to late 1871, when he was finishing the essay on the principle of the conservation of work.

¹⁰ The *Vorträge über Psychophysik* (*Lectures on Psychophysics*) were for Mach a kind of intellectual laboratory where he attempted a first analytic, elements-based point of view (later partly dismissed or reformulated) on sensations; but he also laid the groundwork for his future critique of the ego, and not only that (see Banks 2003, pp. 19-20, 31-32). On the other hand, the *Compendium* closes with a remark that will be crucial in later historical works like the essay on the history of the principle of work and *The Science of Mechanics*: the mechanical conception of the world, Mach maintains, might have exhausted its possibilities and perhaps in the near future the whole edifice of science will experience a "global re-organization" [*gänzlichen Umgestaltung*], possibly based on new foundations from a more profound understanding of the electrical and magnetic phenomena (Mach 1863, pp. 271-272; see also Mach 1872/1911, p. 86).

of the economy of thought (undoubtedly, one of the best known features of his conception) to his historical-critical approach. In this and the following section I attempt to fill such a gap and show that the relation, which I claim exists, completes the picture I have tried to sketch so far.

Starting with his 1882 lecture *Über die ökonomische Natur der physikalischen Forschung*, where he first exploited material that was later reshaped and expanded in the various editions of *The Science of Mechanics*, Mach tended to present his theory of science in the light of the economy of thought and this, in turn, as a result of human evolution. The most concise and clearest formulation of this view probably appears in Mach's 1910 final reply to Planck's attack, written as a kind of intellectual testament, *Die Leitgedanken meiner naturwissenschaftlichen Erkenntnislehre und ihre Aufnahme durch die Zeitgenossen*:

Any abstract conceptual expression, summarizing the properties of facts, any substitution of a number table with a formula or a composition rule, i.e. its law, any explanation of a new fact through others that are already known, can be conceived as an economical achievement. The broader and more detailed the analysis of the scientific methods — the systematic, organizing, simplifying, logical-mathematical construction — the more vividly one recognizes the scientific doing [*Tun*] as economical. ... Darwin's ideas ... were already operating in my lectures at Graz in 1864-1867 and found expression through the conception of competition among scientific ideas as struggle for existence, as the survival of the fittest. Such a view is not at odds with the economical conception, but it supplements and can be combined with this, resulting in a biological-economical description. Expressed as briefly as possible, the following appears as the task of scientific knowledge: *the adaptation of thoughts to facts and to each other*. Every favorable biological process is a process of self-preservation; as

such it is likewise an adaptive process, and more economical [*ökonomischer*] than a process which would be disadvantageous to an individual. All favorable knowing processes are special cases or parts of convenient [*günstiger*] biological processes (Mach 1910/1970, pp. 225-226).

The opening paragraph of Chapter 10 of *Knowledge and Error*, titled “Adaptation of thoughts to facts and to each other”, may serve as a specification of what Mach meant by connecting biology and thought economy into a unified pattern of explanation. Here Mach (1905/1976, p. 120) remarks that “ideas [*Vorstellungen*] gradually adapt to facts by picturing them with sufficient accuracy to meet biological need”. At the earliest stages of development we arguably have very simple answers to basic needs, so that “the accuracy goes no further than required by immediate interests and circumstances”; but even at this primordial level, results might not be univocal, for interests and circumstances “vary from case to case, [therefore] the adaptive results do not quite match [*stimmen die Anpassungsergebnisse verschiedener Fälle nicht genau untereinander überein*]”. So far so good for the biological part of the explanation; but why should this adapting process be conceived as having an economical nature? Mach’s answer is that an important economical feature, involving the least possible expenditure of resources, is simply embedded in biology, for “biological interest further leads to mutual corrections of the pictures to adjust the deviations in the best and most profitable way”. Shortly after he also emphasizes that “economizing, harmonizing and organizing of thoughts are felt as a biological need far beyond the demand for logical consistency” (Mach 1905/1976, p. 128).

What occurs in science for Mach is only more complicated but not essentially different from this very natural (in modern terms, naturalized) process of knowing.¹¹

¹¹ “These processes at first occur quite unintentionally and without clear consciousness. When we become fully conscious what we find within us is already a fairly complete world picture. Later, however, we gradually go over to continuing the processes with clear deliberation, and as soon as this

Let us come back to the *Leitgedanken*. History of science, he continues here, is important because it proves that science and technology have developed, from their “instinctual”, need-based beginnings up to the highest conceptual formulations, in accordance with the guiding principle of thought economy (in the sense specified above). In particular, Mach (1910/1970, p. 228) claims that in his “historical studies on the science of mechanics [(Mach 1883/1960)] and the theory of heat [(Mach 1896/1986)], the biological-economical conception of the process of knowledge has made ... the understanding of the scientific development immensely easier”. Based on case studies that are easily traceable in the above-quoted works, he argues that nothing but the economy of thought has guided scientists toward the generalization of many laws of statics into the principle of virtual displacement and that of virtual work, summarizing many laws of statics (Mach 1883/1960, 49-77); or to replace Johannes Kepler’s three laws with the unique gravitational law of Newton (Mach 1883/1960, 187-189), or again to divide and specify the notion of heat into two concepts — temperature and quantity of heat —, then to introduce more general notions as energy and entropy (Mach 1896/1986, pp. 146-281).

Clearly I do not intend to discuss whether Mach was right or not in claims of this kind; as important as it might be, this is an empirical question that historians of science can debate in light of more thorough information and careful examination. Rather, I want to emphasize that, if my reconstruction so far is right, his stance toward economy of thought seems to highlight a tension with his earlier conception of history as a heraclitean river that neither has an assigned end or *telos* nor follows a predetermined path.

In the 1872 essay, Mach had proclaimed that “history has made all; history can alter all”. Now, with the principle of the economy of thought he seems to imply that the history of science shows operating a standard of progress — perhaps even a

occurs, enquiry sets in” (Mach 1905/1976, p. 120).

teleological principle — in the development of knowledge, for a scientific discipline is more advanced the more comprehensive and economical its laws are, i.e. the fewer the number of basic elements it needs. So, Mach (1883/1960, p. 485) acknowledges a difference in the developmental degree of, say, the highly mathematized parts of physics and what in his times were called *beschreibende Naturwissenschaften* (descriptive natural sciences), such as botanic, zoology, meteorology, geography, etc.: “In the details of science, its economical character is still more apparent. The so-called descriptive sciences must chiefly remain content with reconstructing individual facts. In sciences that are more highly developed, rules for the reconstruction of great numbers of facts may be embodied in a *single* expression”. Thus, in science as a whole there *is* a direction, which is determined by the economy of thought: science can be considered as a “minimal problem” insofar as it strives toward “the completest possible presentment of facts with the least possible expenditure of thought” (Mach 1883/1960, p. 490).

Thought economy and history reconciled

I do not think that this is a real tension, though, and not because the polemics against Planck might have forced Mach to emphasize, and maybe overestimate, the meaning of the principle of thought economy in his epistemology. Rather, it seems to me that the economy of thought and the history of science have emerged and remained, throughout the development of his intellectual path, on different levels.

Thought economy already played a crucial role in the 1872 essay on the principle of the conservation of work, which — according to the 1909 preface — recommended “an arrangement ... of facts” consistent with it (“*eine denkökonomische Ordnung des Tatsächlichen*”: Mach 1872/1911, p. 9). There are primarily two epistemic tasks, according to Mach (1872/1911, p. 55), that are of economical nature: first, the “collection of as many facts as possible in a synoptical form”, e.g. in a law; and second,

“to resolve the more complicated facts into as few and as simple ones as possible”, a process that Mach calls *erklären*, i.e. *to explain*. By iterating this procedure, sooner or later a point is reached where the facts cannot be further resolved. As a consequence, from this notion of explanation it follows that the “simplest facts, to which we reduce the more complicated ones, are always unintelligible in themselves, that is to say, they are not further resolvable”.

Now, Mach continues, although every researcher strives to pursue the most economical way to explain phenomena, not everyone would necessarily agree at what simplest, no further intelligible facts one has to stop:

It is only, on the one hand, an economical question, and, on the other, a question of taste, at what unintelligibilities we stop. People usually deceive themselves in thinking that they have reduced the unintelligible to the intelligible. Understanding consists in analysis alone; and people usually reduce uncommon unintelligibilities to common ones. They always get, finally, to propositions of the form: if *A* is, *B* is, therefore to propositions which must follow from intuition, and, therefore, are not further intelligible. What facts one will allow to rank as fundamental facts, at which one rests, depends on custom [*Gewohnheit*] and on history (Mach 1872/1911, pp. 55-56).

Globally, the economy of thought is ubiquitous and guides human behaviour. But locally, it can be realized in many different ways, depending on individual inclinations and material conditions. What does appear economical *to me*, will not necessarily do so *to you*, because our “histories” (the material conditions that have made of us what we actually are) might be as different as possible. In other words, the economy of thought is not a *feature of history*, but to be sure history, most of all the history of science, reveals it as a *feature of human cognitive resources*, a result of human

evolution which is partly shared with other living beings (see also Mach 1905/1976, pp. 51-64). For this reason Mach maintains that, as we have seen in the previous section, there is no fundamental difference, no rigid boundary, between instinctual, ordinary thinking and the most advanced and abstract forms of scientific theorizing — which is a *leitmotiv* of *Knowledge and Error*.

If understood in this manner, the respective roles of history and thought economy was not something on which Mach changed his mind.¹² A couple of examples from his later works may be illuminating in this regard. In *Principles of the Theory of Heat* (1896), he devotes the entire chapter XXVI to “The economy of science”. Among a variety of historical cases, he comments on Kepler’s approximate law of refraction. He observes that, by the time it was formulated in the *Paralipomena to Witelo* (1604), Kepler “had everything in hand for setting up the dioptrics of Carl Friedrich Gauss. Nevertheless, even after Kepler’s time, many did not do this”. According to Mach, only Gauss succeeded in finding a good dioptrical theory, for he dramatically changed the approach: he “set up the two principal planes and the two principal foci once for all, and did not concern himself any more about the separate refracting surfaces. Thus it is not correct here to say that with the given means only one final result can be attained in one way” (Mach 1896/1986, p. 361).

It seems to me that here Mach is suggesting something like this: even if we concede that, say, both Kepler and Gauss apparently started from the same theoretical premises, and even if they applied the same “economical” thought processes — there are, indeed, a myriad of other historical conditions that may make, and in fact made,

¹² I do not intend to discuss here what is the real origin of the doctrine of the economy of thought in Mach’s conception. Banks (2004) argued that it is “philosophically rooted” in neutral monism, his more general philosophical view. To be honest, I do not find the very notion of “philosophical roots” clear, and I think that a documentary investigation would shed more light on the problem. Unfortunately, as Erik also remarked, Mach’s notebooks preserved at the Archives of the Deutsches Museum in Munich only begin with 1871; but useful indications might emerge from his correspondence as well as through a careful analysis of his relationship with Emanuel Herrmann, which he often quotes as his source regarding the idea of thought economy.

their epistemic pathways different, so that one cannot say *a priori*, as if science were a purely deductive logical system, what will happen next. Such conditions are somehow included in the “facts” to which thoughts must adapt. Let us suppose that two scientists have two different explanations (“complexes of representations” might be an expression more in line with the Machian language) for a single complex of facts; even in this case, they might agree or not depending on several boundary conditions, such as conscious or unconscious inclinations, different background knowledge, etc. Similarly, suppose that one scientist gives a different explanation of the same fact in different occasions; she can do this because the conditions were different in one or another respect. Again, it is matter of relatively changed conditions whether a theory — which is nothing but a “mutual adaptation of thoughts” (Mach 1905/1976, p. 120) — conflicts with another, and which of them will eventually prevail: adaption of thoughts to facts and one another “can ... proceed in *different* ways. Of two conflicting thoughts, the one that seems less important and reliable at the time must tolerate modification to the benefit of the other” (Mach 1905/1976, p. 127).¹³

My second example to substantiate the stability of Mach's views regarding the relation of economy of thought to history comes from Chapter XVII of *Knowledge and Error*, entitled “Pathways of Enquiry”. Here Mach begins by briefly recalling the history of some “scientific astronomic ideas”: the theories of celestial motions, the

¹³ The generally good English translation of *Erkenntnis und Irrtum* is misleading here, therefore I have changed it. The passage in German reads: “*Die Anpassung kann also verschiedener Weise erfolgen. Jener Gedanke unter zwei widerstrebenden, den man zurzeit für weniger wichtig und vertrauenswürdig hält, muss sich die Modifikation zu Gunsten des anderen gefallen lassen*”. This is the current English translation: “Adaptation can thus proceed in different ways: of two conflicting thoughts, the one that seems less important and reliable at the time must suffer modification by the other”. A minor inaccuracy is that the word *verschiedener* (“different”) is italicized in the original text but not in the translation. A more important concern is punctuation: in the English text the colon, meaning that what follows is a clarification of the previous sentence, is arbitrarily introduced — instead, in the original text the sentences are separated by a full stop, suggesting that there is juxtaposition, not clarification. Finally, the phrase “must suffer modification by the other” can ambiguously be interpreted as if the one theory should be modified by the other, whereas this is certainly not the meaning of the German text.

method of epicycles, the fate of geocentric systems, the development of heliocentric system, and so on, up to Newton's gravitational theory. "This development unmistakably shows", Mach comments, "the increasingly accurate mental reconstruction of astronomic facts" (1905/1976, p. 213). However, he adds two important remarks: first, "the process is not finished and may well never be [*Der Prozeß ist nicht abgeschlossen und wohl auch nicht abschließbar*]". Second, even if in hindsight this can be recognized as an economical feat (indeed, "we see the mental reconstruction or description becoming ever simpler and more economical"), the long span of time needed for the most important achievements of astronomy suggests that these "do not rest on inferences of the moment obtainable by means of some formula".

For Mach (1905/1976, p. 222), this can be explained in light of the fact that the pathways of enquiry are far less linear than it retrospectively seems. Scientific developments of this sort "begin with very primitive ideas in the depths of prehistory, but are by no means concluded today... Knowledge is gained on very tortuous paths and the single steps, though conditioned by prior ones, are partly determined by purely accidental physical and mental circumstances as well". Even if the same "economical" thought processes characterize different researchers through the ages, such circumstances are largely independent of us and do not repeat exactly. So Mach concludes: "Schematizing the cognitive stages may perhaps benefit further enquiry when similar situations recur, but there can be no widely effective instructions for enquiry by formula. Nevertheless, it remains always correct that we aim at adapting thoughts to facts and to each other" (Mach 1905/1976, p. 223).

In both examples I extrapolated, from *The Principles of the Theory of Heat and Knowledge and Error* respectively, Mach clearly adopts an economical (or biological-economical) point of view and uses it for interpreting the historical case at hand. This is consistent with the above-quoted claim from the *Leitgedanken* according to which such a perspective made easier for him the understanding of scientific development in

many fields. But it is also evident, I think, that in neither example is he implying a standard of progress or a teleological principle that guides history. Rather, Mach suggests that the one single cognitive process, namely the economy of thought, may result in a plurality of contingent views, for the principle only requires that thoughts adapt to *ever-changing* conditions. They change endlessly because they are part of the heraclitean flux of history, in accordance with his claim in the 1872 essay on the principle of the conservation of work.

Concluding remarks

In this paper, I defended a popular thesis in Mach studies, namely that there is no hiatus but consonance between his approach to history (primarily the history of science) and his epistemology. They are not simply different, juxtaposed parts of his work but two complementary, intertwined expressions of a unique conception. Indeed, his approach may be considered an early example of what we now call an integrated history and philosophy of science, taking for granted that crucial to this is something more than merely the idea of a “history of science into which some philosophy of science may enter ... [or a] philosophy of science into which some history of science may enter”.¹⁴ The way I argued for this thesis, however, is probably not as popular, for my focus was not on the contents of the various stories Mach reviews, which would unveil the epistemological use of history, in accordance with Hiebert (1970) and Feyerabend (1984).

Of course, for Mach history is *also* a “reservoir of ‘modes of thinking’” (using the above-quoted phrase of Heidelberger and Reiter). In this regard, Feyerabend cites a telling passage from *Knowledge and Error*: the most noticeable personalities of the past

¹⁴ The quote comes from Springer's advertisement page for Stadler (2017), in <https://www.springer.com/gp/book/9783319532578>. I have not been able to trace this pithy characterization of the subject in the book itself.

— scientists like Copernicus, Stevin, Galileo, Gilbert, Kepler, or Newton, to mention some heroes in the Machian pantheon — “furnish examples of the greatest successes of scientific research that teach us without pomp what were the leading motives of enquiry”. And, since such examples make “familiar to us in the simplest way” the methods employed (e.g., “the methods of physical and thought experiments, the principles of simplicity and continuity and so on”), history may even be viewed as a collection of inspiring and partially applicable models of behavior that can guide researchers in future investigations into unexplored domains (Mach 1905/1976, p. 165; see Feyerabend 1984, p. 16).

However, more than considering this aspect of the *use* of history for philosophical purposes, I was interested in emphasizing a *structural* level of Mach's discourse on history. In Section 3 I highlighted that both “historical studies” as defended in the essay on the principle of the conservation of work, and the deconstruction of experience into its constituting “elements” conducted in *The Analysis of Sensations*, have the same antimetaphysical function (but, of course, neither of them has *only* an antimetaphysical function). Although they fulfill the antimetaphysical task differently (and have emerged independently in Mach's intellectual development), both historical reconstructions and experience deconstruction remind us that the concepts we arrived at and are currently using are not given for ever. Historical analyses and the analysis of sensations epitomize different types of enquiry, but they both express the same prophylactic attitude against the dogmatic solidification of practical, and provisional, employment of concepts into their unalterable versions. These versions *are* metaphysical because — paraphrasing Mach (1872/1911, p. 17) — they have lost their footing in the ever-changing reality from which they emerge, thereby coming into collision with facts.

A qualifying point for this double-sided approach is that in both cases the relevant constituent materials are transient events. This can be extrapolated, respectively, from

Mach's theory of the elements as advanced in the "Antimetaphysical premises" to *The Analysis of Sensations* (Banks 2003, 2018) as well as from the image of Heraclitus's river of history in Mach (1872/1911). Of course, there is a reason for this. Mach maintains that the entire nature is a heraclitean, ever-changing flux of elements and qualities. Both the historical facts and the element compounds are concatenations of *natural* events, and "nature has but an individual existence; nature simply *is*" (Mach 1883/1960, p. 483; note that the long English sentence divided by a semicolon renders the very concise, meaningful expression: "*Natur ist nur einmal da*"). Why are things there "just once" and do not repeat themselves? For Mach, there is no answer to this — this is simply the way things are (one might say, this is an unintelligible, i.e. no further resolvable simplest fact in the sense of Mach 1872/1911, p. 55). Things would repeat themselves only if the same conditions would exactly repeat (for "in nature only that and so much happens as can happen, and ... this can happen in only *one* way" Mach 1896/1986, p. 360). But Mach would have said that this is just abstraction; in truth, the same conditions never repeat, because all is endowed with individual existence only.¹⁵ Therefore, there is neither contradiction nor tension between Mach's heraclitean view of nature and his commitment as a physicist to the idea of phenomenal repetitiveness, as far as equal conditions are involved. (On this I cannot agree with Banks 2004, p. 25; see also Banks 2003, p. 239).

In so far as history is a natural fact, a chain of unrepeatable, contingent events that have produced a determined result, it does not follow a predetermined path. However, directions may locally appear *within* history, as a result of contingent factors. This explains why some historical events that have taken place, e.g., in the development of one or another scientific discipline, may be economically driven (in the sense of the

¹⁵ "Recurrences of like cases in which *A* is always connected with *B*, that is, like results under like circumstances, that is again, the essence of the connection of cause and effect, exist but in the abstraction which we perform for the purpose of mentally reproducing the facts" (Mach 1883/1960, p. 483).

economy of thought), without the whole of history being so. In the contingency of historical events, humans have been determined by evolution to act economically (one could say, to act economically *is* their own contingency). Case by case, they have been determined by given circumstances to economically react by adapting their behaviour to their needs. That is to say, different humans, being determined by different, unrepeatable circumstances to a certain result of their course of action, may choose different adaptive strategies; “side by side and following one another, [they] will effect adaptation in different ways. One will overlook this, another that” (Mach 1896/1986, pp. 360-361).

And so, what is the conceptual relation of the principle of the economy of thought to Mach's historical approach, to put it as Giere (1973, p. 283)? To be sure, the economy of thought is not the guiding hand of the guiding hand of history, which would make it something like a metaphysical substance, a solidified version of a natural fact. Rather, it is one *content* of the contingent history of (human) evolution, a cognitive capacity that manifests itself historically. And contingent as it is, we cannot even be sure whether it can be saved or, like the ego in *The Analysis of Sensations*, will ultimately be “*unrettbar*”.

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