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G.V. Schiaparelli: from scientific observations to scientific imagination

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Abstract. Starting with a letter exchange between Schiaparelli and the German physicist, physiologist and philosopher Ernst Mach, we discuss some aspects of Schiaparelli's non-astronomical scientific activity. In particular, we give an account of his *Studio comparativo tra le forme organiche naturali e le forme geometriche pure* (Hoepli, Milano 1898), where he sought to represent organic forms and the change from one species to another through geometry. Since his *Studio* provides one of the first examples of an application of mathematics to biology, we analyze it in the light of the geometric-crystallographic approach to biology which flourished in the 19th-century life sciences. Finally we connect his biological interests with astronomy and show how his methodological perspective, which appears also in the letter exchange with Mach, emerges from his scientific activity. In the conclusions we discuss the role of imagination in Schiaparelli's view.

1. Introduction

Though the absence of a comprehensive catalogue of Giovanni V. Schiaparelli's correspondence it is well known by the scholars how wide-reaching his network of scientific contacts was. An extensive study on this subject (hopefully linked to a renewed historical interest in his published and unpublished work) would probably be able to demonstrate Schiaparelli's relevancy well beyond astronomy. In this contribution we will confine ourselves to exploiting this possibility starting with a letter exchange between Schiaparelli and the German physicist, physiologist and philosopher Ernst Mach. Then we will connect the questions raised in the correspondence with some issues of his non-astronomical scientific activity. In the conclusions we will discuss the emergence of his method and methodological considerations from this framework.

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2. Schiaparelli, Mach and a geometric way to biology

In a letter dated April 25, 1898, preserved at the Archive of the Deutsches Museum in Munich and, as a draft, at the archive of Brera Astronomical Observatory in Milan, Schiaparelli wrote to Mach: "I received your kindly letter and the very nice book [Popular Scientific Lectures, second English edition, Open Court, Chicago 1898], the most of which I have just read with real pleasure and usefulness: I see, we agree about a number of ideas. I maintain as a great luck that the most important idea of my book, i.e. that the natural forms depend on a system of parameters, was just conceived by yourself [...]. But I am not the mathematician who can find the fundamental formula by which these parameters will describe the infinite number of forms in organic nature and the change from one type to another one" ("Ho ricevuto la sua cortese lettera e il bellissimo libro, del quale ho già letto anche la maggior parte con sommo diletto ed utilità: vedo che in molti argomenti la pensiamo tutti e due nello stesso modo. Reputo cosa fortunatissima, che l'idea principale del mio scritto, di far dipendere le forme del regno animato da un sistema di parametri, già sia stata da lei concepita [...]. Ma il matematico capace di trovare la formula fondamentale secondo cui quei parametri dovranno determinare le infinite forme della natura organica, e i passaggi loro da un tipo all'altro: quel matematico non sarò io certamente". Schiaparelli to Mach, April 25, 1898, in Deutsches Museum Archive, NL 174/2891).

In his book *Populär-wissenschaftliche Vorlesungen* (whose second English edition Schiaparelli received attached to a letter by Mach dated "Wien 18/IV 98', preserved in the archive of Brera Astronomical Observatory) Mach mentioned a work by the Italian astronomer, *A comparative study between natural organic forms and pure geometric forms* (Schiaparelli 1898), where he sought to account for the morphology of the living beings and the change from one species to another through a geometric system. In Mach's words: "We may hope that, at some future day, a mathematician, letting the fact-continuum of embryology play before his mind, which the paleontologists of the future will supposedly have enriched with more intermediate and derivative forms [...] — that such a mathematician shall transform, by the variation of a few parameters, as in a dissolving view, one form into another, just as we transform one conic section into another" (Mach 1898, p. 257). In a subsequent German edition of this work (1902), Mach added a footnote where he praised Schiaparelli for the hypothesis of a general "geometric way" to the morphology of the living beings in his *Comparative Study*.

3. Geometrizing biology in the 19th century: crystals, geometry and anatomy

Pure geometric form as a form in which "all the points which are part of it are defined by the same construction method" is the cornerstone in Schiaparelli's construction. Such property can be also expressed as it follows: "Given any small but finite part of a pure form, the rest of it is entirely determinate" (Schiaparelli 1898, p. 355). Schiaparelli could soon recognize the crucial analogy between this expression and the morphological principle of the correlation of parts expressed by the comparative anatomist Georges Cuvier by the end of the 19th century: the living beings are organized closed systems whose parts are in mutual correlation, so that given an organ or a small part of it, we would be able to reconstruct the whole structure.

As Schiaparelli worked out his biological-geometric perspective, there was an established and influential tradition in biology about the application of geometry to "natural shapes". A turning point in this tradition was the dramatic breakthrough in crystallography by the end of 18th century. In 1793 the French mineralogist René-Just Haüy established six basic shapes for crystals, relying on strict mathematical relations and assuming that crystals were formed through regular combination of polyhedric-shaped particles which he called "molécules intégrantes". He demonstrated that crystals of a certain kind ("species") could be geometrically related to a common nuclearshape; than he was able to show that the interfacial angles of a given species are constant and characteristic of that species: this was a further development of the "first law of crystallography" generalized by Jean-Baptiste Romé de l'Isle in 1783.

Crystallography provided an analogon of a successful application of mathematics — in particular geometry — to the study of natural forms and its influence over biology has been quite strong throughout the 19th century, even if theories which explicitely compared life and crystals on the basis of "organic crystallization" were fading already by the end of

18th century and resisted by such anatomists as Cuvier and Félix Vicq d'Azyr. The latter, in his *Discours sur l'anatomie*, maked clear that the principles underlying crystallization were "far from being liable of application to the structure as well as to the development of living bodies" (Vicq d'Azyr 1805, p. 23; about Cuvier's position on the organic crystallization theories see e.g. Coleman 1964). On the other hand, the crystallographic attitude to biology was to be increased in the 19th century not only thanks one of the father of cell theory, Theodor Schwann, whose seminal work *Microscopic Investigations on the Accordance in the Structure and Growth of Plants and Animals* (for the original edition see Schwann 1839) provides an important example of this renewed interest, but also on a "methodologic level", where such a mathematical notion as that of symmetry turned out to be crucial (For a comprehensive account of the "crystallographic approach" to the living sciences in 19th century see Stevens 1984).

Comparative anatomy itself played an important role in the history of the relationships between mathematics and biology. The first researcher who pointed out this analogy in the way Schiaparelli and Mach would have done, was the German embryologist Karl Ernst von Baer. In a lecture given in 1821 under the title *Two considerations about the present state of natural history*, he explained the meaning of Cuvier's principle of the correlation of parts in connection with the mathematical property of a curve in a Cartesian plane. As we have seen, the content of Cuvier's principle is that "each part of the body necessarily implies a specific configuration of all the others". Therefore, if we have enough evidence we could, "beginning with the smallest part, develop all the others". Most interestingly, this would not be much different from the mathematician's method, since he "moves from individual points [von Baer obviously meant any small but finite segment] and obtains the whole curve" (von Baer 1821, p. 37).

In developing some of Cuvier's ideas, von Baer renewed his classification of the animal kingdom in four "embranchements": *Vertebrata*, *Articulata*, *Mollusca*, and *Radiata*. Cuvier regarded these "fundamental types" as fixed and believed that comparative examinations could only show similarities and differences in the organs of the living beings. However, they were only due to analogies in functions and did not imply a common history for the organisms bearing these traits (weather shared traits in different organisms which are derived from a common ancestor would be called homologous by the British naturalist Richard Owen: see Owen 1843). Considering embryological development rather than anatomical data (in a way already explored by Haller 1742: about this see Barsanti 1988, pp. 81-82), von Baer maintained Cuvier's classification in four fundamental types, but though he was convinced of the impossibility of any intermediate form between one type and another, emphasized that evolution can occur within each type.

Cuvier's and von Baer's theses as well as the crystallographic approach illustrated above reached Schiaparelli through the Italian naturalist Tito Vignoli, at that time director of the Museum of Natural History in Milan and one of the first readers of Darwin's work in Italy (though he was not a Darwinist himself). Basing on Cuvier's and von Baer's four fundamental types, Vignoli had become convinced that the fine structure of nature was to be searched on molecular level, as crystallography had shown throughout the 19th century. This attitude could open "an investigation about the deepest relations of the living matter with specific geometric structure forms". Therefore, species are nothing but varieties of geometrically determinate forms (i.e. the fundamental types) which are mutually irreducible, as well as crystals sharing the same "nuclear shape" are irreducible to other nuclear shapes. Weather species are steadily arising and perishing, the fundamental types, like geometric forms, "never disappeared": each type embodies a whole series of natural organic forms linked up by "family relationships" and evolution is allowed "only within each fundamental type, but not from one type to another" (Vignoli 1898, p. 264; for more detailed information about Vignoli, see Villa 1917, Badaloni 1990, and Canadelli 2010).

4. Schiaparelli's program: morphology, morphogenesis and the problem of the scientific method

After giving an illustration of the analogy between Cuvier's principle of the correlation of parts and pure geometric form, Schiaparelli worked out his geometric system and explained how transformations from one form into another could take place. Transformations are represented in a Cartesian plane as "deformations" of one curve into another (but constraints must be introduced, so that only discrete transformations are allowed, as it is cleared by Schiaparelli 1898, pp. 368-372. A form or a "family of forms" are specified by an adequate mathematical formula (e.g., conics in plane geomertry: circle, ellipses, etc., i.e. algebraic equations of 2nd order in two variables); the parameters specify the individual shapes; finally, like in Mach (1898), shape "transformations" are described as changes in the parameters. Then Schiaparelli, who was specially interested in an application of his theory in Cuvier's and von Baer's sense, accounted for some aspects of Darwinian evolution as well (see on this subject Guzzardi 2010; an interesting application of Schiaparelli's geometric model to darwinian evolution, also in modern terms, is provided by Freguglia 2002).

In a sense, Schiaparelli's program, which, as we have seen, was deeply-rooted in the 19th-century biology, is typically reductionist — not in a usual physical way, but in a mathematical one. Thus, morphology and evolution of the living beings are nothing but applied mathematics. But most of all, Schiaparelli's theory gave bodily form to a research program devoted to (maybe in spite of Schiaparelli's explicite will) the definition of one or more archetypes in Goethe's and von Baer's sense, and that led its author to the conviction it could cover also the Darwinian theory. In this line of thought, Schiaparelli's geometric system can be described as one of the first examples of a mathematical approach to the general problem of morphogenesis. This research program would be actually developed further in the 20th century by scientists as D'Arcy Wentworth Thompson amongst the biologists, René Thom amongst the mathematicians and Ilya Prigogine amongst the physicists and chemists.

However, Schiaparelli's underlying seminal ideas in theoretical biology cast light also on his ideas about the scientific method in general and specific methodological problems regarding astronomy as the science with which he was more familiar in particular. A further letter to Mach (Milan, February 16, 1900, Deutsches Museum Archive, NL 174/2891) can help us to reconstruct Schiaparelli's approach to scientific problems. Attached to this letter was probably an important contribution to Mars research: *Osservazioni astronomiche e fisiche sulla topografia e costituzione del pianeta Marte* (Schiaparelli 1899). Remarkably, this paper was worked out in the same years of the *Comparative Study*. In this severe communication of scientific data one can find also general statements, as for instance (referring the new observations on planet Mars): "The kingdom of confusion is ended; everywhere shapes become definite and distinguished" (Schiaparelli 1899, p. 295). Remember that in the first letter to Mach, Schiaparelli suggested that in investigating organic shapes "one has to start with the examination of any part of the system where the forms are simple and would easily allow a quite concrete idea about what those parameters should be, in which number they are, and what is the kind of shape modification which is due to the variations of each of them" ("Bisognerà cominciare dall'esame di qualche parte del sistema, dove le forme siano semplici e permettano più facilmente di cominciare a farsi un'idea alquanto concreta di che cosa possano essere questi parametri, in qual numero e quale è la specie di modificazione di forma, che dipende dalle variazioni di ciascuno". Schiaparelli to Mach, April 25, 1898, in Deutsches Museum Archive, NL 174/2891).

This methodological recommendation was expressed in a more general way in Schiaparelli's popular work *The Planet Mars*, which had also a very influential English edition by William H. Pickering (Schiaparelli 1893). Here Schiaparelli discussed the controversial issue of the "Mars canals" emphasizing that even if the hypothesis they would be artificial structures did not imply anything impossible, the fact of their geometric organization cannot compel us to conclude they must be the result of an intervention by intelligent living beings. But basing on the principle that "in the explanation of natural phenomena it is universally agreed to begin with the simplest suppositions", it does not appear appropriate to start with the hypothesis of intelligent beings building "canals" on Mars. In fact, "the geometry of Nature is manifested in many other facts from which are [sic!] excluded the idea of any artificial labor whatever". In Schiaparelli's eyes, big structures of the universe like planet's orbits or the approximately regular shapes of the heavenly bodies actually provided an apt example of a natural geometry; nevertheless, he took into account the organization of organic world too: "Is not that geometry most wonderful which presides over the distribution of the foliage upon certain plants, which orders the nearly symmetrical, star-like figures of the flowers of the field, as well as of the sea and which produces in the shells such an exquisite conical spiral that excels the most beautiful masterpieces of Gothic architecture? In all these objects the geometrical form is the simple and necessary consequence of the principles and laws which govern the physical and physiological world" (Schiaparelli 1893, pp. 24-25/76-77; Engl. transl., pp. 159-160; for an interesting point of view about the methodological consistency of Schiaparelli's ideas in this context, see Hack 1999, pp. 112-116).

We could describe Schiaparelli's methodological recommendation in terms of controlled imagination, which does not exclude "bold conjectures" in Karl Popper's sense in the investigation of natural phenomena. As Mach pointed out in *Erkenntnis und Irrtum* (*Knowledge and error*, see Mach 1905), the hypotheses-making is a complicated process in which play their role both abstraction of the essential traits from the facts (taking the relevant places of Schiaparelli 1893 quoted above as an example, the ubiquity of geometry in nature) and enrichment of connected properties to the facts (following Schiaparelli 1893: organic geometries and the feasibility of organic life on Mars basing on the observation of the "canals"). After all, form differentiation is the best information we have in the study of nature — and that information is widely broadcast by nature itself (Schiaparelli expressed all this quoting a statement by Galilei: "La cortesia della natura", i.e. the courtesy of nature).

Thus Schiaparelli's essay ends with a real praise to the scientific imagination. It is worthwhile to quote the entire subsection in Pickering's beautiful translation: "It would be far more easy if we were willing to introduce the forces pertaining to organic Nature. Here the field of plausible supposition is immense, being capable of making an infinite number of combinations capable of satisfying the appearances even with the smallest and simplest means. Changes of vegetation over a vast area, and the production of animals, also very small, but in enormous multitudes, may well be rendered visible at such a distance. An observer placed in the Moon would be able to see such an appearance at the times in which agricultural operations are carried out upon one vast plain the seedtime and the gathering of the harvest. In such a manner also would the flowers of the plants of the great steppes of Europe and Asia be rendered visible at the distance of Mars by a variety of colouring. A similar system of operations produced in that planet may thus certainly be rendered visible to us. But how difficult for the Lunarians and the Areans to be able to imagine the true causes of such changes of appearance without having first at least some superficial knowledge of terrestrial nature! So also for us, who know so little of the physical state of Mars, and nothing of its organic world, the great liberty of possible supposition renders arbitrary all explanations of this sort and constitutes the gravest obstacle to the acquisition of well-founded notions. All that we may hope is that with time the uncertainty of the problem will gradually diminish, demonstrating if not what the geminations are, at least what they can not be. We may also confide a little in what Galileo called 'the courtesy of Nature', thanks to which a ray of light from an unexpected source will sometimes illuminate an investigation at first believed inaccessible to our speculations, and of which we have a beautiful example in celestial chemistry. Let us therefore hope and study" (Schiaparelli 1893, pp. 24-25/76-77; Engl. transl., pp. 160-161).

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