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REREADING DARWIN. NOTES FOR A CRITICAL HISTORY OF INDETERMINISM

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SECTION 1[1]

It is generally recognised that 1859, the year in which *The Origin of Species* was published, is decisive in the history of science and humanity. This prodigious collection of facts and memories, which was made coherent by an ingenious hypothesis, opened the way to a new vision of the world, shattering the last vestiges of the anthropocentric illusion and bringing natural history into the history of ideas. The most revolutionary fact was the way in which reality was perceived. It was this explanatory paradigm of statistical inspiration that, due to its content and methods, started a whole new epoch in the natural sciences and placed biology at the *avant gard* of scientific research.
Linnaeus had constructed the pattern of classification, Lyell, the timeframe, Malthus had intuited that the process of selection in nature was similar to selection in agricultural breeding, and it was on all these findings that Darwin had reflected deeply. In the

[1] Note of Editors: This paper is a long abstract of a work published on Statistica n. 4, 1974, and still now relevant. In the time, the Author has published many essays on this topic. Among others we mention: – Statistica come metodologia delle scienze naturali, *Rapporti tra Biologia e Statistica*, Contributi del Centro Linceo Interdisciplinare di Scienze matematiche e loro Applicazioni, Accademia Nazionale dei Lincei, Roma 37, 1977; – Ipotesi fatti, teorie nella ricerca biologica: il problema della prova, Ibidem; – Pagine dimenticate di storia della scienza: la disputa tra "menedelisti" e "galtonisti" alle origini della biometria, *Genus*, 1–2, 1976; – Necessità del caso. Appunti per una storia critica dell'indeterminismo statistico, *Statistica*, 1, 1982; – The idea of chances in statistical intuition of natural variability, *Genus*, 3–4, 1982; – Chance and order in a statistical picture of life, *Epistemologia*, 2, 1983; – Ambiguous uses of probability, in *Probability in the science*, Académie International de Philosophie des Sciences, Kluwer, New York, 1988; – Pour une intuition statistique de la nature, in Nouvelles frontières des sciences experimentales (Sèminaire prèsidè par François Jacob), Natio Francorum, Bologna, 1988; – Evoluzionismo e indeterminismo nelle scienze della vita prima e dopo la Rèvolution, *Società Italiana per il progresso delle Scienze*, LX, 1991; – *I fondamenti statistici dell'equilibrio genetico delle popolazioni* (con P. Monari), Martello, Milano, 1989; – *Il tempo e il caso. Una endiadi statistica*, Martello, Milano, 1989; – Certezza dell'incertezza, in *Il mondo incerto*, Laterza, Bari, 1990.

fifty years that have been passed from Lamarck's Phylosophie Zoologique (1809) to the *Origin of Species*, the comparative anatomy and paleontology (Cuvier, Geoffroy Saint-Hilaire), embryology (von Baer) and cellular theory (Schlieden, Schwann) had brought new arguments which enabled a vision of unity in diversity; they were the fabric of a disorganised mosaic, each one of these gave rise to wonder in the face of the "mysterious teleologism" of nature. They were heterogeneous events which Darwin placed within a rational paradigm; a unifying scientific theory. Variability, struggle for life, fitness to the environment were all still independent phenomena before Darwin and Wallace presented their celebrated work to the Linnaean Society in 1858.

It seems that Darwin did not know of Quetelet's work, in effect *Lettres sur la théorie des probabilités* (1846) and *Physique sociale* (1835) went by without leaving a trace alongside the natural sciences of the time. Darwin nevertheless perceived the gradual variability of forms and presupposed the evolutionary phenomenon, which is the historical variation of the species. Inspired by a creationist vision, *Systema Naturae* (1758) postulated the fixity of the species. Linnaeus did not take any account of individual variability represented by the gradual difference between individuals of the same systematic group. It was exactly this variability, at that time neglected, that suggested to Darwin the idea of recognizing in the systemic order the traces of an historic order.

This is a very important methodological suggestion, because it does not deny the principle of classification or the concept of species, but removes the metaphysical shadow which prevented the critical view of the principle of classification. It is an important abstraction especially because reality is not fixed, but evolves. It is a principle that finds its empirical foundation in the variability of characteristics among the individuals of a population.

This principle reinforces the heuristic value of the idea of variability within a systematic group, the idea that the group defines the "type", the idea that "dispersion" in respect to the type is the way of being in nature. With Darwin biology became conscious of a new reality, that is that one cannot understand nature without comprehending its immanent characteristic: variability. And the object of quantitative research is no longer the individual: it is the statistical plurality of individuals.

SECTION 2

The jump from single to group, the passage from an individual to a population is made. Where does this variability come from? Darwin declared his ignorance without hesitation, but this did not impede the fundamental perception: the casualty in the diversity between individuals, the contingency of every variation. The idea of chance entered on tiptoes in the construction of a naturalistic theory. It is true Darwin defined chance as a comfortable expression to admit his ignorance of the cause of every particular variation. But it is also true that his theory negates the necessity of every evolutionary outcome, and brings to mind the naturalistic idea of a contingent reality which is, but might not have been. Of a nature that tries every variation without a final plan.

This is already a form of cautious indeterminism that finds the language of a new science and a new philosophy in this statistical intuition of nature. Here we find the premises of modern molecular biology, where the sequences of aminoacids in a polypeptide infer a truth: chance; a rule: the empirical law of large numbers; a language: that of statistics. The assumption of casualty goes further than Darwin's question on the cause of every slight individual difference or of the more obvious variations which occasionally arise; or as when in physics there are two nearby atoms of uranium, why one explodes millions of years before the other. Questions which today have only one answer, indeterminism. And possibly, the rationalization of a renunciation; but it is also a choice that brings the collective phenomenon to the forefront. It is in collective phenomena that the new science looks for it own rules (those tendency rules by which Boltzmann proposed the kinetic theory of gases overshadowing individual molecular movement because it is inessential). Indeed, even if it were possible to reconstruct the history of a single individual, it would not be possible to infer evolution. It is a *Weltanschauung* that disappears. With this vision, which is the authentic ideological turning point of the empirical sciences, biology anticipates physics and prepares the paradigm of the new mechanics.

Darwin was a spirit free of preconceptions, critically attentive to reality. He did not feel the need to explain natural variability as to him it was already a given fact (as gravity was for Newton); it was the empirical confirmation of the immanent contingency of natural processes. Under pressure to define his idea of chance to horrified conventional criticism, Darwin possibly felt the fragility of his unprovable position; he may have been unnerved by the accusation of having built his theoretical structure upon a metaphysical entity: an unfounded accusation for he who had firmly constructed his theory by always concerning himself with actual phenomena.

If the man in the street rebelled against the idea of having descended from an evolved ape rather than a fallen angel, men of science refuted any interpretation of nature which did not conform to rigid determinism. It was an objection of principle, in which biology (and physics) would not be slow to free themselves when, through the study of micro-processes, genetics found the key which Darwin had already intuited at the level of population (thus proposing a blind indeterministic spontaneity for the origin and evolution of the species), and when the thermodynamics caught the statistical foundations of the phenomena resulting from the concurrence of innumerable micro-processes rebelled against any determinism.

SECTION 3

Darwin saw that each island of the Galapagos had its own type of fauna and flora: not diverse enough to hide the common origins of these species, but sufficient to attribute the differences to isolation. The phenomenon had to be explained by envisaging a natural process able to accumulate negligible differences in a certain direction, over generations. According to the thesis of Malthus, Darwin recognized in the greater mean survival and reproductive rate of those more adapted, the mechanism that led to transformations: a mechanism that is still, and will always be, founded on individual differences. It differentiated form and function gradually, so as to set down unequal initial conditions in the struggle for life: that is to say, a different probability of survival and reproduction over

the generations.
It is then clear that the dimension of population and individual variability have become the two statistical components which were correlated with the appearance of a new species within an isolated group. It would be the discovery of polygenic systems which would draw the complete picture of the biochemical basis of Darwinism, showing the evolutionary potential of these slight, gradual differences on which Darwin hazarded to build into his system. He had statistically intuited that, because they were slight, these differences would have less probability of being damaging. Darwin was unable to know the reason behind all this, but felt that the advantaged variants would have left progeny ready to perpetuate these characteristics.
Today we know the mechanism of heredity which is the basis of modern genetics and that looks like a game of dice. Genetics is a statistical science which has interpreted the evolutionary phenomenon as a probabilistic outcome. It is the process that links the generations. But at the time, Darwin wrote resignedly that the laws that govern heredity were for the most part unknown and he did not imagine the prodigious discoveries that an ingenious monk, Gregor Mendel, had been making with the hybridization of *papilionaceae*.
When in the definitive edition of *The Origin of Species* (1872), a best seller of its time, Darwin argued around the remaining unsolved questions, for more than seven years in the vegetable garden of a Moravian monastery, Mendel had found the first fundamental answers. The forty-seven pages that present the results of his eight years of unwavering research (*Wersüche über PflanZenybriden*, 1866) are a masterpiece of methodological consciousness, of experimental sensitivity, of statistical spirit, but they remained unknown to Darwin and unheard from the scientific world for more than thirty years.
It spoke in a language too far a head of its time, and the few that deigned to give their attention were nothing but perplexed. What could combinatorial analysis and the love of peas have to do and what could possibly explain the floating numeric proportions that were involved in hereditary processes? And, then, what laws could be those of a collective regularity behind which was only wild unpredictability, random matings and indeterminism without hope?
This model of a new type of scientific law remained unrecognized as none had thought to link this gnoseologically determinant tract to the Darwinian Theory. It was too rich in phenomenal implications to allow the methodological message in its contents to be perceived.

SECTION 4

The turn to Darwinism also had the effect of dissolving the last links between the natural sciences and the Aristotelism implicit in those who accused Darwin of not identifying the causes. « Scire per causas » was in fact the principle of Scholasticism and it was again taken up unchanged from new science of the Renaissance. Then Hume arrived to spread scepticism around the "principle of cause". It was a deeply ingrained habit in history rather than an epistemogical category; it was a type of animal faith taken as regula philosophandi. Modern scientific thought reproposed the principle of cause depriving it of every phenomenal necessity and substituting the assumption of inevitable effect with that of probable tendency. It is the mark of a new natural philosophy, in which scientists at the time of Darwin — and Darwin himself — could not have been completely aware.

It is said that Darwin enabled the life sciences to recuperate from a secular backwardness that existed in comparison to physics. At that time, physics was a science principally constructed on a deterministic paradigm, but to speak of a Darwinian determinism deprives the Darwinism of its most innovative characteristic, that which signals a decisive change in the history of naturalistic thought. Assuming evolution to be a deterministic process is equivalent to admitting, in abstract, that two completely identical natural worlds subject to the very same laws and evolving side by side at one point in time, would present themselves as identical in a future time.

It does not seem this is the spirit in which Darwin interprets the differences between similar species living in the Galapagos, as they are islands characterised by habitats hardly diverse enough to attribute a systematic significance to the evolutionary diversity which had occurred. Darwin wrote that during the voyage of the Beagle he was profoundly struck by the way in which certain species differ only slightly between those of other islands of the group when it was clearly evident that neither the action of environmental conditions nor the will of the organisms (in particular the plants) could provide an explanation.

Genetics would confirm that evolution is unpredictable particularly because it is an historical phenomenon; would demonstrate that two identical couples of a genetic system will not necessarily be such after an assigned interval of time; would explain through the indeterminism of molecular phenomena the process that differentiates every evolutionary line; would render explicit the statistical characteristic of the natural world as interpreted by Darwin.[2]

Whatever the idea of chance accepted from Darwin was these results carry his theory outside of the paradigm of Laplace — where chance is only the scientific meaning of our ignorance standing before unknown deterministic laws.

We linger on this aspect of a lack of depth in the theory of natural selection, not to reject the authoritative interpretations that place the intuition of Darwin in the ideal world of Laplace, but to rediscover — following the suggestion of Schroedinger —[3] the significant depth of admiration of Boltzmann for the author of *The Origin of Species*,

[2] Evolution is an indeterministic process especially because of the enormous disproportion between the number of possible genetic combinations and the number of individuals which reproduce. The unrepeatability and unpredictability of every evolutionary process comes from this. It is the same type of indeterminism that is found in the positioning of cards when the deck is shuffled.

[3] For Schroedinger the law of large numbers is the backbone of the two theories, whose communal character is found in a spiritual tendency of the rational thought of the century, of which Darwin and Boltzmann were the highest exponents.

according to whom the statistical law of large numbers[4] offers a syntactical and empirical trace both to the theory of Darwin, and new thermodynamics. Natural selection begins with a random, multidirectional, non teleological process and produces an evolutionary chain probabilistically oriented by selective environmental factors. In much the same way as the mechanical theory of heat describes an indeterministic process in which the phenomenal result is a statistical regularity.

But there is more: Darwin's paradigm identified a natural mechanism able to favour the deviations from average behaviour, to be passed down and diffused. So the thermodynamic processes become statistical laws which tend entropically towards the chaos of the molecular population, moving in a single direction practically without return (a converging process). In the same way, the irreversibility of the biological evolutionary process is guaranteed by Darwinian selection: when an organic characteristic is not inconsistent with environmental pressure and moves forward, it does not go back (a diverging process).

SECTION 5

The new and determinant fact was therefore the new scientific interest on natural populations: a methodological line that appeared to Darwin's intuition previous to the elegant formulations of Maxwell, or the schemes of Bolzmann (and of Gibbs). Therefore, a new indeterministic vision came to substitute the mechanist determinism that had its maximum expression in the system of Laplace.[5] Considering heat to be molecular movement, Maxwell (1860) tried in vain to represent it according to the classic laws of mechanics and convinced himself of the opportunity of a statistical treatment of the results of these movements. It was a pragmatic choice that was adopted, that did not stop him from imagining his ambiguous little devil intent on following the path of every single particle until it violated that second principle that would become the prototype of statistical law. The work of Maxwell was to be the last flash of determinism, the final illusion of that *Weltanschauung*. The statistical interpretation and the recourse to probabilistic models quickly assumed a completely different significance. Boltzmann (1872) explained that the movement of a single particle was found to be insignificant rather than unfeasible. They are the statistical properties that together form the object of science. Even if all the initial conditions of a system are noted, it would not be possible to deduce the state of the system at another different time: one can only draw conclusions on the distribution of probability of possible states.

It was intuition of this type which, in that happy autumn in the Galapagos,[6] in front

[4] Unpredictable events at the individual level become stable at a collective level: this is the sense of the law of large numbers, an empirical principle so deep-rooted in experience that, when in large numbers of cases a deviation from the combinatorial prediction is found, a type of instinct warns that a systematic factor is present rather than a probabilistic theorem.

[5] « Une intelligence qui, pour un instant donné connaìtrait toutes les forces dont la nature est animée… ».

[6] It was October in the year 1835.

of a non-coincidental evolutionary line, enabled Darwin to uncover, *more statistico*, his most complete explanation.

Science would quickly discover that the laws of chance are not only found in the probabilistic schemes of the type that Boltzmann used to propose his scandalous parallels between combinatorial calculus and physical reality. It had to wait, nevertheless, for the audacious affirmation of Exner (1919) on the statistical character of all natural laws because doubts about the deterministic dogma — a convention exchanged for reality — began to spread through the world of physics regarding molecular and atomic events. The theory of probability entered into physics at first to determine the grammar in which submicroscopic events seemed to express themselves. Together with probability theory, the idea of chance also became essential for a simplified description of complex phenomena. The debate which ensued opened the question as to whether these themes might have ended with humanity: the concept of chance that is supported by the new science is only a comfortable paradigm to represent phenomena characterized by an indecipherable determinism, or does it, on the other hand, express the becoming of a nature that is indeterministically realised?

There is an eternal dilemma between ontological and epistemological meaning in scientific thought. It is noted that men such as Planck or Einstein judged the probabilistic interpretation of the quantum mechanics to be transitory, while for men such as Heisenberg or Born this interpretation is definitive. The example of de Broglie or Schroedinger is emblematic, where wavering hesitations before the indeterministic paradigm revealed the drama of conscience when faced with a choice that was no longer only a question of scientific theory. Indeed, whether or not God plays the dice with the world — according to a famous exchange of wits in correspondence between Einstein and Born (1944) —[7] it is scientifically irrelevant: and it is certain though that the physicist who investigates the elementary particles of matter, or the geneticist who studies the elementary processes that make up the species, cannot themselves avoid playing dice.

SECTION 6

Lamarck saw the evolution of the individual, Darwin of the species in populations. Lamarck was inspired by an ethically satisfying hypothesis of work, in which the single individual becomes the subject of evolution; Darwin instead considered the variability inside the species, produced by unprogrammed, casual phenomena, that is mutations and recombinations. On this variability natural selection intervened ex post on the variants which were less suited to the environmental conditions: the individual is therefore the object of the adaptive process in the evolution of the species. These modify themselves through the differential reproduction from around groups. The passage from the individual to group, from direct and mechanical environmental action to the random recombination of characters in the homospecific population under the demographic

[7] The dispute between two giants had no appeal to logical argument, but to instinctive attitudes, to innate sentiments.

pressure, according to probability laws will be the argument of the great theoretical synthesis by Fisher (1930), Haldane (1931), Wright (1932) and partially by Chetverikov (1926). The mechanism of natural selection appears today in its indeterministic and statistical completeness. Biophysics actually says that it is a necessary implication according to the principles of thermodynamics.

In the evolution of species, chance is essential. Darwin was conscious of it, but he hesitated to assert it. In certain pages of Darwin one can sense a type of reserve, *in re gnoseologica*, to go further than the confines of an argument which had already gone against the dominant thought which all science had been modelled on for centuries. To be sure, the explicit affirmation of a new *modus intellegendi* of the events would have risked compromising the scientific future of *The Origin of Species*.

In a letter to Lyell (21 August 1861) Darwin asked why one should speak of variability as having been preordained and guided more than does an astronomer in discussing the fall of a meteoric stone. Would not be called this theological pedantry or display?

The sense in which Darwin speaks of Chance reveals this agnostic background, which was long distant from the future debates of current philosophy. A new epoch of science had begun. In the same way that classical science had the physics of Galileo who found his ideal message in the experimental method; the new science was endowed with the cultural ideas of evolutionism and found its interpretive code in statistics.

The *modus operandi* of Darwin is not statistics in a technical sense. The theory of natural selection is instead an exemplary expression of a statistical understanding like *modus intellegendi*. In fact the idea that Darwin drew on the suggestive and cynical paper by Thomas R Malthus is statistics. The logical process that describes evolution is statistics: the struggle for life and survival of the fittest means differential reproduction rate.[8] The mechanism through which the environment intervenes with its life forms by means of selective pressure on the population is statistics. These implications guide the biologist in the calculation of the accidental variability of a species, of which only a minimal part actually comes into existence and give the biologist an interpretative grammar where the single random mutation fuses in the large numbers through the generations. Darwin himself, with brilliant understanding, recognized an extremely important element of outcome in the numbers.

The theory of survival of the fittest also has statistical significance, however Darwin never affirmed that natural selection always assured the success of the most adapted: it operates in most cases and this is enough to assure the effectuation of the evolutionary process. It is a law of tendency that betrays the statistical assumption of the differential reproduction of genotypes. This is true also for the concept of overpopulation borrowed from Malthus and associated with naturalistic observations of excesses of plants and animals (Buffon, Lamarck, ...). These are the principal concepts of the Darwinian vision which, through a careful and open minded rereading, reveals its true methodological soul.

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[8] Always becoming more statistical, the evolutionary theory renewed the lexicon: struggle for life (not necessarily in a gladiatorial sense, as Huxley made clear) came to mean differential rate of reproduction.

SECTION 7

The approach of the accidental to necessity is a new sign of the times in natural philosophy: the times of statistics. Physics was soon to discover a statistical soul in submicroscopic events, as did biology. The great Mendelian turning point saw the beginning of a new biology, the genetics. It finds the stochastic origin of the accidental variability between life forms; in the statistical laws of the transmission of characteristics from one generation to another.

The experimental genetics would demonstrate the multifactorial processes which give rise to intraspecific variability, in which Charles Darwin saw the first condition of evolution: a great scientific and conceptual synthesis of Mendelism and Darwinism was completed.

Darwin had linked intraspecific variability to an accidental, unprogrammed process generated by hereditary recombinations through sexual reproduction. This meant that a Mendelian process assured the permanence of genic frequencies, while a Darwinian process favoured the fittest combinations in a given environment so that such frequencies could vary. Successively, the discovery of the genetic code and its universality favoured the interdisciplinarity between the biological and non biological sciences.

The random micro events that, altering the genetic heritage, are the origin of variability show how natural selection can realize through populations the congruency between organism and environment and set down chance at the root of the phenomena of life. If a specific cause is recognizable, the relationship between the initial microscopic fact and its collective macroscopic consequences is contingent.

All of this represents a leap in the syntaxes, a change of paradigm that — thanks to Mendel — characterizes biology long before the new quantum mechanics followed the discovery of the corpuscular and discrete structure of the physical phenomena. According to Born, it has no deterministic prejudices and is completely statistical. During his studies on the distribution of heat in the luminous spectrum of an incandescent body, Max Planck was forced to formulate the hypothesis of a discrete emission of energy. It is significant that he developed his memorable theory on heat radiation — the birth of quantum theory — just a few months before the rediscovery of Mendel's laws (a delay of thirty five years!) the biological reality presented itself in its essential.

Biology was therefore arrived at the quantity through the classes that is through entire numbers, even before physics was to be seen through a world of discrete numerable entities.[9] A great part of biological events which until those times was impossible to formalize, could now be treated quantitatively. The classificatory nature of biology no longer obstructed its mathematical treatment: instead it represented the statistical premise.

While in physics the statistical vision followed the decomposition of the macro processes in micro processes, in biology it affirmed itself through two moments: when Darwin saw the population as a collective reality between the individual and the species,

[9] Schroedinger said that for the study of the origin of species the theory of mutation is like quantum theory is for physics: variation is not based on continuity, but on small jumps.

and when the Mendelian studies of the genetic components of evolution brought to light hereditary behaviour like that found in the law of large numbers, which is their empirical foundation. After attention had been moved from the individual to population of a same species (communities of individuals endowed with a common genetic pool), the gradual differences between the species become the object of new naturalistic research. This sense of plurality and contingency is the epistemological mark of the Darwinian Theory: the outline of the beginnings of a first great, indeterministic sketch in the history of scientific thought.[10]

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[10] Boltzmann, who investigated the indeterminism of kinetic theory of gases, called the nineteenth century Darwin's century.

SUMMARY

Rereading Darwin. Notes for a critical history of indeterminism

On carefully re-examining the theory of natural selection, one can see in it the first nondeterministic hypothesis in the history of modern science. As such it also exemplifies the use of statistics as a *modus intellegendi*, as an empirical language for all phenomena which cannot be interpreted in terms of strict teleology. According to this interpretation, the work of Darwin turns the course of science towards a new way of knowing, of interpreting nature, the way that with Mendel's Laws has given birth to a deep renewal of research in biology, and has also gradually come to characterize all modern physics starting from the statistical thermodynamics of Boltzmann.