TIME AND CHANCE: A STATISTICAL HENDIADYS*

Italo Scardovi

1. "Αἰὼν παῖς ἐστι παίζων πεσσεύων": "Time is a child playing dice". More than twenty-five centuries have passed since Heraclitus first used the vivid, pictorial synthesis of this aphorism to illustrate the enigmatic intertwining of 'time' and 'chance'. With the passing of time, this metaphor so aptly chosen by the philosopher of παντα ρει to link casuality to 'becoming' has taken on ever more profound, and universal, meanings.

Time and chance are the intellectual coordinates of a new form of knowledge, a new way of interpreting our natural world. This new canon is inflexibly statistical in nature. Determinism, timelessness and reversibility still characterise the physics based on the differential equations that lie at the foundation of Newton's laws of mechanics and Maxwell's laws of electrodynamics, alongside the tensorial equations of Einstein's laws of relativity and even the fundamental equation describing waves in quantum mechanics. Indeed, this mechanics has come to be based on frequency distributions and average values, turning to statistics while at the same time abandoning the traditional certainties of the universe described by Newton and Laplace. Indeed, the universe they described was indifferent to the concepts of time and chance, and viewed probability as a useful epistemic expedient, rather than the expression of an inherent intrinsec casualness. We are faced with Laplace's assumption: a vision of chance as an "imaginary cause" evoked out of ignorance of the "true causes" considered in sound philosophy.

Chance has no place within this sublime paradigm, and uncertainty is simply the result of a lack of information, of approximate measurement. Time, in turn, is an external, independent variable, and as such is nature's time detached from history, in a universe that becomes little more than a sort of neverending set of building blocks in which the past also provides an image of the future: a motionless background upon which the human comedy is acted out: a comedy which is instead irreversible and 'becoming.'

And yet this is not the case in other sciences that on the contrary attempt to describe this 'becoming', where time and chance have gradually taken on an es-

* Translated from *Tempo e caso: una endiadi statistica*, Atti della XXXIII Riunione Scientifica della Società Italiana di Statistica, 1996.

sential value. It is a time inherent to all the phenomena and the processes that involve populations, such as those of elementary particles, molecules or living beings: from the univocal time of thermal agitation or radiactive decay to the plurivocal time of non-linear dynamic systems, to the evolutionary time of the becoming of life, a non-symmetrical time of processes rendered irreversible by their inherent casualness. This intrinsic casualness is at the heart of the individual variability essential for the evolution of species. Joiming the physics of heavy bodies attracted by gravity and falling through space, as described by Newton, and the physics of events over time driven by probability, as described by Boltzmann, the dynamics of heat have offered an image of a 'becoming' that is irreversible and independent from its initial state and subject to the same rules which come into play when a deck of cards is shuffled, and evolutionary biology has instead added, in playing with the concept of 'chance', an unyielding unpredictableness. The time of the evolution of life, Darwin's time, is the time of a nature which becomes history, and is characterised by an immanence which becomes contingency.

The scope of these conceptual paradigms goes beyond natural phenomena. Indeed, these paradigms represent not only separate moments in scientific thought (from time as geometry to time as history, from the time required for the falling of heavy bodies at a constant speed to time modelled on the idea of 'becoming' of processes): they are thus schemes of reference and linguistic paradigms through which it is possible to formulate a rational representation of different realities.

2. The question of whether time is an objective reality or simply a condition of the human spirit, a property found in the natural world or merely an illusion produced by the mind, has been a constant dilemma throughout the history of human thought, from Aristotle to Einstein. What's more, attempts to respond to this question have been even more heartfelt since the natural sciences began to be faced with a time of φύσις, which they found to be no less irreversible than that of πόλις: the time corresponding to the expansion of our universe, the time characterising the transformation of life on our planet. It is not, time as symbolised by the isochronous swinging of a pendulum, of the rhythmic reappearance of the Sun, time reduced, as described by Kant, to a causal order, from which Einstein's theory of relativity would remove all absoluteness. Instead, we are faced with a concept of time dictated by phenomena, a consequence of their converging towards the most probable state or of their chaotic divergence. And it is chance – statistical chance – that breaks the symmetry of time, giving a direction to these processes.

If one accepts the idea voiced by Saint Augustine that time is ineffable, in the truest sense of the word, it is also true that chance is no less difficult to describe. Does it belong to an ontic or epistemic category? Does it represent the grammar of nature, or the grammar of science? Is it the "thought of things", as described by pre-Columbian civilizations, or human thought? As Mallarmé put it in one of his poems, "Each thought expresses a roll of the dice". Often it is still myth which substitutes for fact, superstition which wins out over reason. A reason which often somehow hesitates in take if advantage of a natural philosophy using a jargon which seems to revert to the vague language of the ancient oracles – the language of probability – and talking about time and chance, both of which are, while seemingly undefinable, essential to scientific knowledge, and yet have long awaited a coherent gnosiological order, made difficult by the fact that the two are indeed characterised by a remote extraneousness.

In the simple terms of our everyday language, we tend to attribute to chance only highly improbable events rather than highly probable ones. The latter events are seen as necessary, obligatory, expected; while the former are seen as accidental, fortuitous, unexpected. They each, however, constitute a different moment of a single reality. And if there is a shadow of randomness in the path followed by a gas molecule, in the decay of the nucleus of a radioactive atom, in the mutation of a nucleotide or in the encounter of two recessive alleles, it is also true that it is present in the collective result of these individual accidental events: there is an increase in entropy, a given half-time, or genetic variability. The resulting statistical regularity – the macroscopic predictability – is based on the fortuitousness of single microevents, on their reciprocal independence and on the invariance of the probability (which is not null) of their occurring.

Indeed, individual gas molecules respond to the mechanical laws of motion, which are reversible and invariant with respect to time. On the contrary, a large set of molecules becomes an irreversible process proceeding in the direction of the most likely order, in a time which, upon passing, cannot return. This contradiction is truly fascinating. To better grasp its sense, Boltzmann imagined enumerating the "microstates" compatible with each "macrostate" – just as Galileo did it more than two centuries earlier to illustrate the answer to a question regarding the ancient Roman gambling game known as "roll-ten", which was played with dice – and attributed the same odds, that is, the same degree of statistical probability, to each microstate. Thus, if through this calculation, the founder of modern science was able to explain why, when three dice are thrown many times, the total number eleven is a more common outcome than twelve, in his turn the founder of modern mechanical statistics was able to link the 'becoming' of the system to the number of microstates and derive the probabilities of the corresponding macrostates.

3. Paul and Tatiana Ehrenfest's exemplary probability model clarifies the statistical nature of the second principle of thermodynamics: the tendency towards temporal irreversibility of phenomena in which innumerable reversible elementary events concun. It gives an amusing image in terms of bipartition, drawing by lots, of a population of diligent fleas trained using two extremely patient dogs. A tendency towards a distribution equilibrium ensured by the randomness and equiprobability of the single events, which are independent of each other: in other words, by chance. The movement of each particle (the movement of each flea) is not irreversible; the irreversibility regards the set. The unpredictableness of the final position of a single element and the predictability of the partitioning of the set after an adequate number of Bernoullian drawings define the statistical nature of the process: the greater the number of members in the initial set, the more the collective result will occur, independently of the initial state, so as to consent the inherent randomness to give rise, in successive drawings, to the statistical equilibrium characteristic of large numbers. When dealing with large numbers, a new elementary event added to the total number observed does not alter the statistical properties of the set as a whole; it can, however, in leaps, have the effect of deviation when dealing with small numbers. It is the many individual fortuitous events that produce collective regularity: an almost certain result, as is almost certain the 'disorder' of a deck of cards shuffled at length: this too is a macrostate compatible with an extremely large number of microstates.

Thus, it is the statistical component of the processs that distinguishes the future from the past, turning microscopic reversibility into macroscopic irreversibility, and explaining why the fleas tend to jump from the dog with the most fleas to the dog with the least, even though each individual flea, at each drawing, has the same odds of being extracted. And thus Boltzmann reproposed the kinetic-combinatorial principle enunciated by Clausius, according to which isolated systems tend spontaneously towards the most likely order, with oscillations that will be slighter and with a final outcome that will become less uncertain the higher the number of elements involved. And yet, the movements of the molecules always respond to the classic laws of dynamics, as do the orbits of planets or the rolling of dice.

If n is the number of elements (be they fleas or particles), $n+1$ outcome distributions ("macrostates") are possible, and each of these macrostates has its own probability calculated according to the number of concurrent "microstates", all of which are equally probable. None of these microstates has a probability equal to zero: therefore, even a final state in which all of the fleas are on the same dog (in other words, in which all of the molecules have gone over spontaneously to the same side) is not impossible: it is simply the least likely among all the possible outcomes (because it is represented by the smallest number of microstates: only one). What's more, the larger the population, the less likely this outcome will be. And yet, in a sufficiently long series of attempts, one would find, at random among the other outcomes, the rarest and least likely outcome. Over a sufficient period of time, the system will pass through every possible ordering, as foreseen by the "ergodic hypothesis". Nevertheless, the likelihood of the process reversing itself, inverting the time arrow, becomes ever smaller as the number of constituents increases.

This process takes place over a period of time that is intermittently marked by a series of draws: at each draw the system will tend, in terms of probability, to distance itself from its initial order, with a magnitude S –"entropy" – proportional to the logarithm of the number W of microstates ($S = k \log W$), which represents a measure of the quantity of chance and time that has entered the system, in its irreversible movement towards an increasing level of "disorder". The entropy of the system, be it thermodynamic or flea-ish, increases by virtue of what Boltzmann refered to as "molecular chaos", pinpointing the objective, intrinsec casuality which lies at the origin of the strange contradiction to which his controversial "H theorem" gave an upsetting answer. It is probability that gives time its direction, observed Boltzmann; it is time that generates probability, Prigogine would later add.

It is chance that mediates the passing from the dynamic representation provided by classical mechanics, the mechanics of reversible systems, to the thermodynamic interpretation of processes that come into being with the passing of time: time thus becomes an "operator". Driven by chance, a process will converge towards the state of maximal entropy, regardless of its initial conditions, which the system "forgets". A number n of particles can be subdivided into two sets containing $n1$ e $n2$ members in $(n!)/(n1!)(n2!)$ ways: which reach their maximum for $n1=n2$. Indeed, after a sufficiently long series of draws, the number of units atttributed to the two groups will approach $n1=n2=n/2$: an equilibrium that will become ever more likely as the value of n increases.

This interweaving of time and chance, of 'becoming' and fortuity, is thus linked to the number of elements. The effect of one depends on the intervention of the other. Thus we have, not an "antithesis", but rather a dialectic process, or better yet, a hendiadys – a statistical hendiadys – as the bases upon which to form a statistical theory of time and chance.

4. The laws of science freed from the constraints of mechanical natural philosophy are statistical laws: they do not foresee the single event itself, but rather its probability. Nor do they codify the trajectory of a molecule: instead, they draw conclusions regarding the collective result of the movements of a group of molecules. These laws do not predict which atom nucleus is about to decay, but rather calculate the half-time of an aggregate of radioactive atoms; they do not anticipate the genotype that will emerge from the merging of two heterozygotes, but they can determine the probability of the possible genotypes; they cannot predict the path of evolution, but are able to identify the algorithms for the combinatory events through which life is transmitted and renewed across the generations of a species. And even if, at a certain moment in time, all of the co-ordinates of these phenomena were known, it still would not be possible to deduce their state at a different instant. All that can be outlined is the partition of probability of the various possibile states, when they are all prefigured.

The condition of independence among the various single constituent events, all of which have an equal probability, is essential to the assumption of randomness. In the absence of this condition – without the distribution equilibrium which is the result of large numbers – what could we reply to the question, "How can the atoms of a fragment of uranium decay over time in such a way as to distribute their statistical frequencies along a curve descending asymptotically on the x-axis?" Or to the question, "In the game of *roulette*, how does the small ball know that it must stop on the number zero at least once every 37 times it rolls around the wheel so as to preserve the casino from financial ruin?" Once again, we are faced with the same casual combination of factors that ensures the uniform azure blue colour of the sky, that regulates the molecular variations in the density of the atmosphere, that distributes molecules uniformly in the air around us: an event that is immensely more probable than any unequal partitioning and that, the less equal it becomes, the more it becomes improbable. It is, once again, chance that keeps this eventuality at bay, hiding it in the large numbers, rendering it virtually negligible in our experience, allowing us to blithely breathe on, unaware of the risk we run of asphyxia due to ... improbability. In thermodynamics, this type of phenomenon is defined as "practically impossible" given that its degree of realisability is trifling when viewed in terms of the finite orders of magnitude in our experience. And the adverb practically implies a measure of time and of chance. Once again, we find a conditioning from habit: which suggests the idea of causal necessity, as insinuated by Hume.

It is the fact that we are accustomed to regularity that enables us to distinguish the real world from the world of dreams, and to establish the boundary between what is possible and what is not, between what exists and that which is only imaginary. If dream activity were ordered and coordinated, how would we be able to recognise it? As Pascal once wrote, "A craftsman who every night dreamt, for twelve straight hours, that he was king, would not be unhappier than a king who dreamt, every night, for twelve straight hours, he was a craftsman." And what would happen if, in our dream world, a sort of ideal anti-world behind Alice's looking glass, things which only rarely happen on this side of the mirror frequently came true? Would it not be enough to madden a computerised Faust, in making his terrible pact with a stochastic Mephistopheles to enjoy eternal improbability by inverting the arrow of time?

5. The antithesis between causality and casualness, between ontological and epistemological choices, widens the topic to the very limits of scientific knowledge. And it is not insignificant that chance, which as Cassirer put it is "a true chameleon able to change to any colour", is at times defined as an absence of causes, and yet at other times as an indiscernible multiplicity of independent causes. From combinatory chance as described by Boltzmann to the concept of chance delineated by Born, which arises at the quantum level at the moment in which it is observed and measured, to chance as pondered by Monod, which stumbles upon necessity, which disrupts a repetitive order and saves the species, to chance as interpreted by Prigogine, who unleashes chaos as a creator weaving a new alliance between man and nature... The question of chance has been looming ever since science began to discover the algorithms of statistics within the algorithms of life, and, in the logic of probability, a logic in Nature. The response of science has been probability calculus: mathematical theory and, at the same time, a metaphor likening it to a game.

Causal explanations are undoubtedly more satisfying (as the ancients put it, "*scire per causas*"), and linking the cause of one phenomenon to another, dividing them into categories, more readily allows us to recognise phenomenal antecedents (once again we find the ancient rule: "*omne quod movetur ab alio movetur*"). Cause, in other words, has a reassuring superficial materiality of its own. This is not, however, the case for chance, the content of which is more inexplicable, and less sensitive to our demand for certainty, to our search for some unknown necessity. Likewise, it is true that every attempt to define randomness will digress into metaphysics. And yet, is that not what happens when one attempts to coherently define causality? There is no doubt that the best bet would be to limit oneself to the epistemological dimension – but for both concepts. And yet we might ask ouselves, as Poincaré once did, "...if that which we call chance is perhaps nothing more than a different name we choose to give our ignorance." Among the positions of those who choose it as a provisional convention, while waiting for the hidden causes to be deciphered, and those who take it as an intellectual point of no return, the "abacus man", the craftsman of the method who hazards these arguments, is tempted to find satisfaction in a saying from long ago which puts common sense into words, hidden in a page of Aristotle's *Analytica priora*: "None of that which happens by chance happens in consideration of something else." Randomness thus is an absence of purpose.

Perhaps the most widely accepted definition is "causal" in nature; indeed, this is a recurring version in the history of thought, from Spinoza to Cournot, from Bergson to Monod and to many others: chance (the "essential chance") is the encounter of two independent deterministic plots. The idea is furthered in the example of a roof tile falling on a passer-by, or of the fatal blow from the hammer which slipped from the hand of the carpenter Dubois and hit the head of Dr. Dupont. Chance, essential chance, is present even in the impact between an object from outer space and our planet (as in the catastrophe of Tanguska) or in Horace's encounter with a nuisance, rendered immortal in his 'ninth satire': "*Ibam forte via sacra, sicut meus est mos, / nescio quid meditans nugarum...*". Here, the word – *forte* – expresses the fortuitousness of that fatal encounter perfectly.

In truth, not even these intersections seem to exclude a deterministic interpretation (or even a finalistic interpretation: chance as fatality). And one could perhaps set up a "system" including both causal plots, so as to interpret them as not independent. Thus we have the intersection of two disjoint deterministic trajectories that at times takes on the appearance of fortuitousness, but at other times the guise of necessity, according to one's ideal frame of reference. Where one observer might see essential fortuitousness and indomitable contingency, another may see hidden necessities, masked by what appears to be random evidence. What then are reference frames, if not formal allegories which are not always freed from the component of impressionability that is ever present in the relationship between man and chance?

If we draw a ball from an urn containing one hundred thousand balls numbered biuniquely with the first one hundred thousand natural numbers, whatever number is extracted we will remain indifferent. However, if after the ball is drawn, we discover that the ball was the only red one in the urn, and that all the others were white, we can't help but be surprised at the occurrence of this event to which all of the schools of thought in the study of probability – as well as our own common sense – attribute only one possibility in ninety-nine thousand, nine hundred and ninety-nine. And yet, it is the same ball, the same object: the same one whose extraction, in the first scenario, we would have greeted with total indifference. The same fact can thus take on different significance simply because our parameter for judging it changes. What is it, then, that makes an event important in our world, if not our own expectations?

6. We need to ask ourselves whether the antinomy between "cause" and "chance", that is, between the ontological dignity of the former and the epistemological temporariness of the other, finds some justification in the prevailing of everyday wisdom over scientific knowledge, of custom over rational thought: only in this can the idea of cause be justified. It is an idea that seems to almost disappear the more the antecedent phenomena are described in detail. Each single fact is an unrepeatable *unicum*, and it is the non- reproducibility of the conditions in which the events occur that gives the idea of cause a conventional meaning. Without using classification abstraction, the concept of cause is no less indefinite than the concept of chance; rather it simply conforms more to a custom refined by natural selection, by the evolutionary history of the species, of every living species: a mindset that has arisen *regula philosophandi*. Perhaps we attribute ontic value to it because it is more anthropomorphic: a sort of "familiar truth", as described by Stuart Mill, suggested by the regularity of certain recurrences: classification regularities and, as such, knowledge. Otherwise, how would it be possible to avoid the trap of unrepeatableness in identifying events which are causes and those which constitute effects, without interpreting them as classes of empirical entities which are equal and yet different? If all of the antecedents of an occurrence were rigourously defined, without simplifying idealizations and without linguistic allegories, how could we postulate the unchanged reproduction of a given combination of factors?

Along the same lines, the idea of chance can also be intended as a causal multiplicity, with each "multiplicity" itself unrepeatable. This repeatability regards macroevents, and derives from the fact that there are numerous compatible microevents for any one macroevent. This is also the case in the outcome of a roll of a single die, if we consider the aspect of it stopping with a certain side up: although this result would be reproducible, not so the particular causal sequence leading up to it. "One cannot step into the same river twice", warned Heraclitus, and Leibniz would later add, "Two perfectly identical things can, in reality, never exist." It is our way of thinking which renders them identical – it is a question of language. And thus common names are invented, and the same is true for natural numbers, and for the classes on which the sciences base their laws, transforming physical objects into 'mathematisable' abstract objects. No event repeats itself without reducing facts to symbols, things to ideas and plurality to typologies.

It is in this context that the idea of chance is formed; even if it is less immediate, and less common. Also for this reason, Kolmogorov resolved to delineate an axiomatic theory of probability able to avoid, in its reduction to syntax, excessive semantic uncertainty. Indeed, it is to Kolmogorov, as well as to Chaitin, that we are indebted for the attempt to define randomness as an "algorithmical uncompressibleness" of a sequence of natural numbers; randomness, in the sense that it cannot be reduced to a conventional order, to a rule of sequence expressed by a number of constraints less than the number of terms. Fortuitous, then in the sense of "not regular". From here we arrive at the terms of the problem: a message is random when the number of constraints is not less than the number of data; and at the conclusion (as Gödel would have reasoned): the randomness of a sequence of elements cannot be demonstrated. "God sometimes plays dice with natural numbers", as Chaitin commented. However, while this may perhaps be considered a contribution to the theory of numbers, it does not help us in the definition of chance, identified in the absence of any order. It follows that the tables of "random numbers" – which according to Marc Kac do not need to an errata corrige – should then be given a different name.

The question is whether the characteristic of randomness should be searched for in the structure – or instead in the process – from which it derives; if an event, a piece of data, a sequence can be termed fortuitous based on the way in which they present themselves (their phenotype, as it were) or instead in their genesis (in other words, their genotype). The sequences of the numbers to the right of the decimal point, in the number π, or in another irrational number such as $\sqrt{2}$, or the irrational and transcendental number *e,* are uncompressible, and thus can be considered casual in the aforementioned sense, at least until the algorithms which describe their origin are found, so as to summarise them with a single piece of information. Chance, once again, is the incapacity to discover hidden regularity. If I toss ten times a coin that hasn't been rigged, the number of possible outcomes of one of the two sides of the coin ("heads", for example) is a discrete random variable ranging from the natural numbers zero to ten. Of the eleven possible outcomes, each of which having its own probability (not null) there is also the possibility that "heads" may be the outcome of every toss of the coin: a perfectly compressible sequence that can be reduced to a very simple rule, to a single piece of information. Although due to a random mechanism, this sequence would still be considered absolutely not casual.

This is not the case for the statistical abacus, where one could, instead, suspect that the outcome is not entirely casual, considering its slight a priori probability, in the hypothesis of the equiprobability of elementary events: less than one in a thousand. This empirical criterion is, obviously, not defining, and yet, there should be no reason to doubt, for example, the fortuitousness of the result "five times heads, five times tails ", the probability of which is more than two hundred and fifty times greater but which could occur, in any case, in the series of coin tosses, in just as many other possible sequences: "microstates" all of which are compatible with the combinatory "macrostate". If we indicate the outcome "tails" with a 0 and "heads" with a 1, some sequences of these numbers are perfectly compressible, while others are not. We thus return, again, to the question of whether the root of randomness lies in the form of the piece of data, or in its history, a question that also lies at the heart of inductive statistics.

7. The identification of aleatory in "irregularity" thus introduces an irresolvable ambiguity. And it is not alone, in that it alludes to aleatory in order to understand "unpredictability": the unpredictability of an event that is not univocally determined. Once again, we are faced with a misunderstanding. There are, in fact, unpredictable deterministic phenomena, as well as predictable indeterministic phenomena, which are made foreseeable by their intrinsec randomness, as is the case in casual irreversible processes for which the second principle of thermodynamics is a unifying paradigm: the outcome occurs, over time, out of a sort of statistical necessity whatever the original state may have been. It is the same statistical irreversibility of the ordering of a deck of playing cards after they have been shuffled. Using a similar analogy, Boltzmann drew the conclusion that "... probabilistic hypotheses reflect a natural state." Max Born wrote that, "Nowadays our way of thinking has been turned upside down: chance has become the key notion, while mechanics is an expression of its quantitative laws; and the great evidence of causality in everyday experiences, with all of their attributes, is still explained quite convincingly by the statistical laws of great numbers."

On the contrary, a perfectly determinate and deterministic dynamic system can be unpredictable in terms of projection over time, due to the effect of its dependance on its starting conditions, and on any slight variation in them. What's more, deductions regarding the future based on current data cannot go beyond a certain degree. Causality does not necessarily imply predictableness: indeed, even a minimal accident, a negligible imprecision in the starting conditions of a dynamic system, is enough to cause significant variations over time, thus making even the most determinate and deterministic of imaginable states unpredictable. At the beginning of the last century, Poincaré had sensed this, in posing the "problem of the three bodies" and revealing the impossibility of an exact calculation – after a certain period of time – of the ordering of a system composed of more than two heavy bodies attracted to each other with a force directly proportional to the product of their masses and inversely proportional to the square of their respective distances, in accordance with Newton's law of gravity; Hadamard later found proof of this in the geodesic flow of a surface with a negative constant curvature.

Chaos theory would take into account the exponential amplification, over time, of the effects of previous fortuitousness, and of the unavoidable distancing of the system from its original state: seen in this light, the future is no longer an image of the past. "Why is it that many people who find it perfectly natural to pray for rain – or sunshine – would think it ridiculous to pray for an eclipse?" wondered Poincaré. And the answer is: it is a question of how we measure time. The state of chaos in our atmosphere is produced over an extremely short lapse of time, while that of a planet is reached over an extremely long period of time, by our reckoning, with our historical timescale: a timescale which had led mankind to believe that everything that does not seem to change during the unit of measure applied by given observers is unchanging. "No rose remembers having seen a gardener die," recalls an aphorism of Fontenelle, which Diderot was quick to cite when faced with someone unwilling to concede that reality is a question of 'becoming'.

In our everyday language, the words "chance" and "chaos" both evoke an image of disorder, irregularity and unpredictableness; and we tend to equate them, while they may represent, in truth, different realities. Chaos can arise in deterministic systems – non-linear dynamic systems – leading to an exponential divergence of the minimum approximations in some coordinates of a system. Indeed, it is referred to as "deterministic chaos", an expression which would appear to be a contradicion – an oxymoron, if you will. From the chemistry of processes to fluid dynamics, from meteorology to astronomy, we can find physical systems which are subject, over time, to increasing chaotic complexity. At the origin of this complexity, at times, may be chance. Poincaré identified it in the long-run indeterminism inherent to the evolution of dynamic systems, as does Ruelle, today. Chance is rooted in the initial conditions.

8. A die is cast. Its rolling and flipping from one side to another can be split up into a series of casually determined events. Dice are cube-shaped, and have mass, and so are subject to the laws of gravity, elasticity, friction and inertia; even a slight variation in the angle of incidence is enough to produce a different outcome. Is this chaos, then? Perhaps. And yet not divergent chaos: in a long series of tosses, the relative frequencies of the outcomes for each of the six sides of this hexahedron (which can be distinguished with symbols which are not significant in terms of their impact on the laws of physics which come into play) converge towards a shared probability. Is it perhaps an "attractor"?

Where can we pinpoint chance in a die rolling on the table? Is it the random onset which threatens a deterministic system – as put by chaos theory (the "butterfly effect", as Lorenz called it) – disrupting an order, and undermining its predictableness? Or is it the essential element of a non-deterministic system, where it introduces, within the proper empirical dimensions, regularity and predictability? If we change the formal model, the answer changes. Yet, does this provide us with proof of the ambiguity of the problem? Not necessarily. To questions such as "How does the planet Pluto know the Sun is there?" or "How does an an elementary particle make us believe it has passed through both cracks?", physics is not always able to supply univocal answers.

Chance somehow seems to slip away, to be impossible to express. The harder we try to grasp and latch on to it, in the attempt to give it some physical semblance, the more it seems to hide: first, behind this 'nothingness' (as in the quantum leap of an electron, or the decay of an atom's nucleus: spontaneous events which are by definition without cause), then behind a multiplicity of factors, each of which is in itself deterministically expressible. It may be, in turn, that chance is the generator of determinism: an overall statistical determinism. This is true also in the case of Brownian motion: each single particle has an irregular, chaotic behaviour, which the set of particles has not. This is the case even for a burst of photons against a plate of glass, which may or may not be deflected. This probability lies at the root of the different phenomena of light, even of those most commonly observed.

Chance itself, therefore, does not carry any greater risk of disorder, irregularity, unpredictableness than it does of order, regularity and predictableness. It has a converging and stabilising effect with great numbers (as in the theory of kinetics), but a diverging and wandering effect in the presence of small numbers: this is chance in genetic drift, a chance bearing innovation Rather than attempt its exorcism, the natural sciences have learned to treat its effects rationally: chance does not evoke, in itself, the absence of laws, which would amount to a violation of the canons of science. Science is still a search for invariants, and the invariants of this science are probability distributions.

It is chance which causes the convergence, in probability, of processes for which the law of entropy offers a general paradigm: processes that will come into being over time thanks to a sort of intrinsec statistical necessity, towards a state of equilibrium that is a sort of "statistical attractor". Each dynamic constituent of the system is invariant with respect to time, while the resulting thermodynamics is not. We thus have a collective statistical result. And it is in fact the statistical component that breaks the symmetry of time, giving a direction to processes linking the macro- and microworlds, and offering an image of nature in which order and disorder, certainty and uncertainty, causality and randomness become intertwined in moments which are not so much alternative as complementary.

9. Due to the effect of the intrinsec combinatory randomness of the reproductive process, two biological populations having the same genome (for example, as a result of cloning) and living in the same environment but separately from each other will tend to undergo evolution over time that does not coincide. With an increase in constituents, the populations will become ever more independent from the initial conditions, which will, instead, still have a greater effect in very small populations. Chance can thus be a factor of instability or stability, according to the degrees of freedom of the system. It would appear that the more complex a system is – the greater the degree of chance in it – the longer the time necessary for it to return to the initial state will be, and the less improbable it is that a pre-existing configuration will again appear. Small populations are therefore very sensitive to their initial conditions and diverge rapidly due to the erratic effect of genetic casuality in small numbers, the so-called *random genetic drift*. With great numbers, on the other hand, a genetic accident produces its effects over much longer periods of time. Nonetheless, the two populations will in any case follow divergent evolutionary pathways. Are we faced with deterministic chaoticness, or indeterministic randomness?

Seen from a mechanistic standpoint, two genetically identical isolated populations living in identical environments should evolve in parallel; from the standpoint of statistics such populations cannot remain identical because genetic randomness will cause them to inevitably differentiate as different generations come into being in a random, combinatory manner. And yet, a dogmatic determinist might observe that if the populations diverge, it will be due to the existence of hidden diversity in the initial conditions which increases with the passing of time. A sceptical indeterminist might reply that diversity would in any case enter into play, underlining that we are faced with unreconciliable gnosiologies. Whatever the frame of reference, evolutionary biology remains a path which is not linear and not finalistic: a process which works, as François Jacob suggested, much like a "bricoleur", attempting a do-it-yourself project involving the assembly of parts designed for other purposes. It is the indeterminate nature of "bricolage" that makes this immanent situation accidental. The unpredictableness of its future order is thus not an expression of insufficient knowledge or of a postulated impossibility to learn about the profound phenomena of life.

Divergence and unpredictableness do not occur in the indeterministic 'coming into being of life' alone: two dynamic physical systems can also follow trajectories which are increasingly divergent over time. Two very near trajectories, in obedience with rigorously deterministic laws, tend to move away from each other at an exponential rate, so a to make the future unpredictable beyond a "temporal horizon". A system of three differential equations is sufficient to give rise to chaotic irregularity, which will be more dependent on the initial conditions the lower the number of degrees of freedom. The future is hidden behind chaos and the "bifurcation" of a process which, although at times latent in that it is hidden behind an average value, is always possible.

Another important distinction must then be made. There is the indeterminate nature of the individual event, which immanent casuality translates into statistical determinism due to the inertial contribution of numerous individual events: this is the case in heat mechanics, as well as in radioactive decay. There is the indeterminateness of dynamic systems, the chaos generated by a small event amplified by the deterministic chain: as can be seen in hydrodynamics and meteorology. Finally, there is the statistical indeterminism of sets: this is the case in evolutionary biology. We are faced with a paradigm that is essentially populationistic and accidentalistic which finds its primary ratio in synchronous individual variation.

If we represent a dynamic system (or a statistical set) with a point in a hyperspace defined by a number of coordinates equal to the number of constituents, if the system is instable (or the set tends towards a state of increasing probability) the point will move along more or less regular trajectories, according to the number of degrees of freedom. As this number increases, we witness a decrease in the probability that any segment of the trajectory will be repeated. This is irreversibility.

These different models may appear to be different expressions of the same universal paradigm. Deterministic divergent chaos looms, the higher the number of free coordinates in a system; entropic chance drives the process further towards the most probable state on the basis of the number of individual constituents, that is to say, the dynamic coordinates of the single events. Both introduce time, a physical time, with a past and a future: thus, they can offer a canon with which to interpret social events which are in and of themselves collective and at the same time 'becoming' along a timeline of their own.

10. As Prigogine argued, the irreversibility and complexity of processes can take on a transdisciplinary meaning, helping to bring together different cultures, and offering us a methodological model able to help us understand natural events as well as the 'ups and downs' of human life. If it is true that natural philosophy, which is inspired by mechanistic dogma and rests upon absolute and unbreakable laws, excluded the social disciplines from the realm of scientific thought (and these disciplines, in any case, had left no stone unturned in the attempt to imitate that gnosiology), science freed from the constraints of determinism moved methodologically towards research regarding human phenomena. This form of science regards populations, for which it is possible only to adduce statistical properties and foresee not the single events, but rather their probability. And yet, some social sciences – which rely so freely on the formal tools of statistics – now appear more hesitant, almost as if the waning of deterministic certainties had reduced their aspirations of science, leading to an identity crisis that in a certain sense almost seems to express a mourning for a paradigm that has been lost.

In the events characterising human society, the bio-evolutionary paradigm and the paradigm of deterministic chaos can offer useful points of reference. Even in our human "*res gestae*", an occurrence which may outwardly seem negligible can become significant at the collective level. Our social system, and for that matter any social system, willl generally have more degrees of freedom than would dynamic physical systems. Why? Because a further element of indeterminateness comes into play: the "human variable", which is charged with instability and unpredictableness. It is this element, and not so much that of historicalness, that distinguishes the inductive inferences made in the social sciences from those made in the natural sciences. In human society, relationships among individuals can determine a one-way shift in equilibrium within a group, speeding it up and slowing it, in the direction of an essential non-linearity. Wishes, intents, motives and passions as well as emotional, cognitive and mental processes can all move in unexpected directions; and the contribution of an individual can overlap with a sort of collective will. It is just this factor of "volition" that constitutes the extra element of unpredictableness that conditions and confuses historical-social theorisation. It is this variable that makes Skinner's question ever more timely: "Why is it so difficult to treat human behaviour scientifically?"

The prediction of social phenomena must reconcile the impossibility of adducing abstract and isolated systems with the need to postulate the stability of the variables identified. This is the case in the projection towards the future of a past described through a time series either deterministically or stochastically, it is the case in the statistical and econometric models that include time, in particular multiequational models, which are also exposed to the chaotic divergence hidden in the approximation of measurements, whence forecasts are limited to the short run only, because the assumption of stability loses its value inertially when it distances itself from the starting data. And without postulating invariance, no forecast is possible.

Attempts to search for invariants in the social sphere have been made throughout the history of rational thought. These include several assumptions in neoclassical economics, and Comte's idea of "social physics", which Adolphe Quetelet had outlined, *more statistico*, in searching for, "in the great body of society (...) set laws as unchangeable as those that govern heavenly bodies (...); laws that are independent of time and of the whims of men ...", the laws of a world without a future and without a past, much like the universe described by Newton, or species as described by Linnaeus. In this way, statistical probability became the logic and the ethic of an arcane collective fate intent on deciding categories, but indifferent to individual destinies, which it left to chance, so as to get around the 'Kantian' alternative between human freedom as self-determination and natural determinism as the rationality of nature. It would be the ultimate illusion of deterministic way of thinking. Soon after a new non-episodic meaning would begin to be given to probability, as it began to be understood that even the physical constants in the universe are not unchangable, in the same way that living species are not.

11. The past and the future are not symmetrical in a non-static society, in a reality which is coming into being and not reduced to a nomological system. Society is characterised by 'becoming' as are, with an order of magnitude reflecting their respective timescales, the universe and life itself. And while in the fields of physics or genetics predictions are a prefiguring of a probable distribution of the states of nature compatible with a present state, in the fields of economics, demographics and sociology it's clear that no more can be done, despite the fact that utilitarian expectations remain unsatisfied. Induction, that is the prediction of a 'probabilised' space, is a feature of science; decision-making instead belongs to the sphere of strategy, in other words, the choice of a point in that space. Also in the case of studies of human society, rational prediction is translated into a range of future possibilities much like an open fan, despite the fact that the practical reason for forecasting is the need to decide, and thus to close the fan.

An induction that ventures through time takes on different methodological frameworks depending on whether or not one postulates processes which are casual and deterministically configurable, or if on the contrary a non-deterministic image of reality is adopted. With the first assumption, forecasting is an attempt to anticipate what the the future holds; in the second case, it is an attempt to identify the space containing alternatives compatible with the 'becoming' of phenomena. This space, or part of it, is all that can be rationally represented. Each identification of a point in that space becomes a prophetic presumption: not because it challenges the gods, but because the future appears unnecessary and non-univocal.

In so far as it is a rationalisation of uncertainty, every prevision-induction makes future a virtual horizon of possible realities (not all of which are equally possible) starting from the current reality intended as something which has come to exist and as something which is only now coming into being. With the fall of the illusions that characterised the golden age of Laplace, this is the philosophy regarding prevision in all areas of knowledge: from one domain to another, what instead changes is the time scale, the difference between the times of human expectation and those required for the happenings in our world. If the future is not determined univocally by the past, because "*natura facit saltus*", in humans too, a model that faithfully travels through the past again runs the risk of not anticipating the future. Such a model would in any case need to take into account numerous variables (and indeed today's computers make it possible to consider hundreds), but in doing so the system becomes more and more exposed to chaotic instability, and thus to the unforeseen that breaks continuity.

This coming together and comparing of ideas, in the evolutionary intertwining of nature and history, of research on the natural individual and the social individual, provides a glimpse of the premises upon which to base a possible methodological κοινη, on the topic of mankind, able to overcome a certain supposed separateness among cultures, and a certain lack of communication among those working in different sectors of thought. These sectors have historically passed from phases of vague attraction to phases of strong repulsion, much like the porcupines in a German tale of long ago (re-told by Schopenhauer) who, pushed by the bitter cold to huddle together for warmth but immediately obliged to move away so as not to prick each other, were thus condemned to an eternal attempt to reach an impossible equilibrium.

12. The attention paid to casuality is certainly a characteristic of the playful spirit of our times, not so much as a rational reflection but in the sense of. an irrational challenge. Our vision of chance is often mythological, rather than logical; magical rather than scientific. What's more, new totems and taboos are constantly turning up. The more the world appears to be indeterministic, the more our relationship with chance becomes unscientific, and we take refuge in the cabala. Where one finds randomness, can there be myth? Myths are mechanisms we use to suppress time, as wrote Lévi-Strauss. They would also seem to be expedients with which to escape, or to get around, chance. What's more, the feeling of panic in the face of unpredictableness is a result of a sort of unfathomableness of the designs of the gods, which we attempt to foretell using complex rituals and at times to avert, cloaking casuality in sacrality. In the past, chance was entrusted to the transfiguration of a cloud, to the tossing of an astragalus. Never, in those cultures, would we have imagined that nature could trust to chance and roll the dice to decide the fate of profound phenomena involving matter and life in time.

Looming over this discussion is an unsettling question: is scientific knowledge is no longer able to provide us with certainties, is the laws of nature are no longer absolute and binding, if that particular mathematics is not "the" mathematic of the universe, if that particular knowledge, laws and mathematics are an abstraction, a model, a language: that is exploitable and conventional idealisations, among the many which would be possible, confronted with a contingent reality that is coming into being and open towards many futures, what then is the place of man in nature and what is the place of science in human adventure? From here, we arrive at the attempts to remove the accidentalistic canon with which phenomenal reality is interpreted; on the contrary, this has been the inspiration for the elegant decisionistic re-posing that is so in fashion today: i.e. the transposition of knowledge in expediency, of research in strategy, that has found a suitable conceptual matrix in philosophical pragmatism, as seen in Dewey. Already Pascal, one of earliest theorists of gaming, which lies at the origins of probabilistic calculus, proposed his famous "*pari*" on transcendence in terms of utility, not in terms of truth: from the calculation of probability to the calculation of earnings, from the reason behind the laying of bets to bets made in reasoning.

From Leibniz to Laplace, from Einstein to Thom, not to mention others, there has been a desire in the discussion of the idea of chance to recognise a clever attempt to get around the limits of the human mind: the subjective and contingent reflex of an underlying deterministic reality. And it would be Einstein himself, who had contributed so greatly to the probabilistic intuition in mechanics grew on the *quanta* used by Planck to decipher the radiation of a blackbody, who alone (or almost alone) among the founding fathers of quantum physics would continue to believe that in the near future it would be possible to understand the "real" causal laws hidden in statistical statements, and thus find, even in the microworld, the reassuring certainties of classical determinism.

And yet, if one day (notwithstanding the enunciation of von Neumann, of Bell's inequality) the arduous and unthinkable discovery should happen, that is, if we were to discover what Einstein referred to as "the hidden variables", and the statistical reading of the entire physics of the microworld were to remain a fortunate epistemological choice, a useful formal alternative to the rediscovered mechanistic representation of the elementary constituents of matter, none of this would in any way alter the statistical framework of the other natural sciences. This is true starting from evolutionary biology, in which the immanent indeterministic spontaneity of 'coming into being' would appear to be unyielding, and time and chance play a constitutive role.

In the hereditary processes which lie at the origin of natural variability, there is a neverending game of dice underway played by living species, intent on handing down their genetic code while at the same time renewing it. There is no hidden variable to uncover, no parameter to identify, in that the constituents are known, the algorithms are definite; each with its own esssential casuality, from the non-invariant replication of nucleic acids to the independent assortment of chromosomes, to the diploid outcome, in the zygote, of the encounter between two complementary gametes.

All of these are factors in individual variability: the variability in genotype upon which evolution is based. And even if specific causalities were identified, there would in any case still be the contingent relationship between each microevent and its macrodimensional consequences, in terms of fitness of the living organism to its environment. A deterministic interpretation of evolutionary biology would reduce it to a necessary one-way path, with everything about it implicit in its initial data: individual synchronic variability would make no sense, nor would the vast unfinished reserve of latent variability encoded in the genome of a species, which the species will use – randomly again – only in part, toying with the combinatorial alternatives of linear polymer chains and their extremely high number of virtually possible outcomes.

It is just this intrinsec casuality that gives rise to variability in genotypes and to the resulting variability in phenotypes: a natural process which is elegantly formalised in the "theorem of the genetic equilibrium among populations" in terms of statistical probability, of axioms in the theory of probability. In the 'coming into being' of life forms, the toying of chance with necessity, over time marked by the passing of generations, reaches the highest degree of indeterminateness. Once again we are faced with "statistical necessity", which is neither univocal nor convergent. This statistical indeterminism tells us about the unpredictableness of what is to come, the fortuitousness of what has already come into being, and the lack of necessity of that which exists.

By contributing the idea of a non-necessary contingent natural reality to scientific thought, through the hendiadys of time and chance, statistical intuition regarding nature has threatened the anthropocentric illusion of a universe created for mankind. "All that is necessary exists", might have exclaimed a thinker such as de Maistre, in melding together metaphysical certainties with mechanistic science. Naturalistic indeterminism suggests a different assumption: what exists does not conform so much to that which is necessary, but rather to what is probable. This is true also for our species: human beings are a product of a history: one of the many possible moments of evolution of one of the many possible evolutionary lines. It is a history which does not seem to inscribe itself in a 'becoming' defined as a fulfilment of the inevitable.

13. Werner Heisenberg once wrote: "The probability function contains the objective element of the trend and the subjective element of incomplete knowledge." Indeed, it is that "objective element" that determines the irreversibility and predictableness of realities made up of a large number of reversible and unforeseeable elementary events, and this is a "statistical" element. Linking entropy to probability, Ludwig Boltzmann had in reality supplied an answer that is essentially statistical, in spite of a prudent lexical choice (the "dynamic states"). This was a courageous choice for his times, and one which was for many years argued against in that it appeared to be too revolutionary. We know that Albert Einstein, who had used this choice to decipher Brownian movement, rejected, as would have any good disciple of Spinoza, any nondeterministic view of nature, a reality which was not, in its design, 'becoming'. Spinoza's *Deus sive natura* left no room for time and chance. The theoretician of relativity put it: no more than "an illusion, a subjective albeit obstinate impression", and, in keeping steadfastly to his assumption of an unchangeable, rational, certain nature, he had ended up incorporating in his grand relativistic system a "cosmological constant" so as not to illustrate, coherently, an expanding universe. Within just a few short years, when Hubble's spectroscopic observations became known, he would describe this choice as the biggest blunder of his life.

Every age has seen its share of ideologies on the opposite front, alongside but in contrast to the hypothesis of an immanent stochastic nature. In these theses, both the portrayal of nature as trifling with chance and science as adducing probabilty were equally unattractive to finalistic and deterministic philosophers. Thus, in the "age of enlightenment" – to give a quick example – the hypothesis of natural casualty was rejected with the same resoluteness by the encyclopaedist d'Alembert ("nature ignores chance" was his assumption) and by the conservative de Maistre ("one should never even speak of chance" – was his warning). Even the absurd persecution which geneticists underwent in the Stalinist empire of the Forties and Fifties – a drama no less sad or vexing than that suffered by Galileo and many others like him, but lived out in our century – bore the mark of dogmatic determinism. Kolmogorov, who rebelled in defense of Vavilov and Cetverikov (heroic figures who paid for their scientific work with their lives), was silenced. No form of natural randomness could be admitted, in that absolute ideology, and probability as described by Mendel, could have no role in a doctrine that attributed every single characteristic of humanity to social and historical circumstances. As Jean Rostand once wrote: "Fanaticism is always at the service of untruths; but even if it were to serve the truth, it would still be detestable."

The dispute regarding the objectivity and subjectivity of chance embarasses an entire culture no less than does the question of objectivity and subjectivity of time. A long tradition of thought has demanded that randomness be excluded from the context of rationality. Intuitions regarding a phenomenal role for chance, which had only been touched upon in classical antiquity (just think of Epicurus, or of the idea from which Lucretius developed his *exiguum clinamen*), or in the Enlightenment (for example in Diderot's famous "*Entrétien*"). However, these were only isolated flashes of light, which long remained in the shadows of a monumental philosophy ready to reject the hypothesis that reality is not the only possible one, that an event is that which can also not happen and that at best what can be foreseen is not the event, but its probability.

This rejection of chance can be found throughout an entire dominating line of thought, and it is striking that Anatole France wrote: "Chance, after all, is God," almost imitating: Bossuet, a thinker who can be considered distant from him not only in historical terms but also in terms of their ideas ("what men deem chance is God's design"). It is a return to Leibniz's assumption ("to mankind, the harmony pre-established by Divine Providence appears to be chance") and to Spinoza ("nature, a work of divinity, does not allow contingency"), not to mention Kant. Little more than four years ago, Jean Guitton wrote, "What we call chance is nothing more than our inability to understand a higher order."

Is this a form of ethical or aesthetic suggestion? A suggestion which has fascinated even certain molecular biologists of our times, who, in conceding the evident combinatory casuality of the processes that generate biological variability, expressed them with three words: *Generator of diversity*, obtaining the acronym *God*. It is a God who truly seems to be playing with dice and who – perhaps – can't resist the chance to load them. Still today, there are strong examples of rebellion and rejection. One name will suffice: Réné Thom, the theoretician of catastrophes, who accuses indeterminist scientists of apostasy and desertion, launching anathemas, such as: "*Halt au hasard, silence au bruit* ...". This is a reaction to the loss of certainty which accompanied the ending of the great system of thought that had inspired the science of necessary causes and inexorable effects. A causal deterministic model is certainly more reassuring, when the aim is to identify a necessity or significance in every event; when the expectation is that the principle of cause must apply to all natural phenomena, none excluded. No answer has, however, yet been found for the insidious question at the heart of statistical mechanics: if the single molecules of a gas obey the dynamic laws of motion, which are invariant with respect to time, how is it possible that in a vast set of such molecules, each of which is causally determined, an irreversible process can develop along the time arrow, without the input of a new casualness?

14. Other questions without a deterministic answer still remain. For example: "Where can we discover whether or not there is some secret plan, be it causal or final, that decrees the encounter between two haploid gametes to form a genotype? Or the plan of the spontaneous mutation of a nitrogenous base that alters a segment of DNA? And, how can the effect of this secret plan on living beings, on a given population, or on a species, be pre-established? And if it were to exist, how could that secret "decision" be expressed in a language different from that of probability?

It is just this ineffable language that speaks to the dice rolling and bouncing, to the ball spinning around the numbered roulette wheel. And it is clear that, hand in hand with these events, determining their outcome, there must be a same entity: The play that decides which of two radioactive atoms close to each other will decay today and which a thousand years from now, or that pushes an electron into a new orbit and awaits the consequences of that quantum leap.

Thus, we must rely upon a new canon if we wish to understand all of these different realities. This canon will allow us to interpret a greater knowledge born of the re-discovery of time and chance, revealed as enigmatic mediators between what is possible, and what is real. This re-discovery cannot help but offer striking, awe-inspiring emotions, as found in the reflections of scientists and the intuitions of poets. In voicing his oppposition to the proud certainty of the Victorian age, Thomas Hardy described time and chance as blind judges, and artfully expressed their profound intertwining in two beautiful verses: "Crass Casualty obstructs the sun and rain,/ And dicing Time for gladness casts a moan ..."

Faculty of Statistics ITALO SCARDOVI
University of Bologna

RIASSUNTO

Tempo e caso: una endiadi statistica?

Tempo e caso sono le coordinate intellettuali di una nuova conoscenza della realtà naturale fondata sul divenire dei fenomeni: realtà molecolari entropiche, decadimento atomico radioattivo, processi chimici instabili, sistemi dinamici caotici, divenire evolutivo delle specie viventi. Paradigmi, tutti, in cui il tempo e il caso agiscono come operatori. L'intrecciarsi di tempo e caso passa per l'intermediazione di una componente statistica dipendente dal numero dei gradi di libertà: condizione essenziale ai processi empirici che si avverano lungo la freccia del tempo nel senso di una crescente probabilità. Il caso spezza la simmetria del tempo rendendo irreversibile il divenire, legando il micromondo al macromondo e offrendo una immagine della natura dove ordine e disordine, causalità e casualità, certezza e incertezza coesistono. Così la congiunzione di tempo e caso non è un'antitesi, bensì una endiadi: una endiadi statistica.

SUMMARY

Time and chance: a statistical hendiadys

Time and chance are the intellectual coordinates of a new knowledge of natural reality founded on phenomena characterised by 'becoming': entropic molecular processes, radioactive atomic processes, chemical processes, chaotic dynamic systems and biological evolution, are all paridigms in which time and chance act as "operators". The intertwining of time and chance is tightened by the intermediation of a statistical component, depending on the number of degrees of freedom, which is a phenomenal condition linked to empirical processes and to the directions of the time arrow which points towards an increasing probability. Chance breaks the symmetry of time; by making the 'becoming' irreversible, it links the microworld to the macroworld and offers an image of nature where order and disorder, causality and casualty, certainty and uncertainty coexist. Thus, the meeting of time and chance is not an antithesis but rather a dialectic process or, better yet, a statistical hendiadys.