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CONTINGENCY AND NATURAL ORDER IN EARLY MODERN SCIENCE

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XIV. *The Immanent Contingency of Physical Laws in Leibniz's Dynamics* (by Tzuchien Tho, *University of Bristol*)

XV. *Ars experimentandi et conjectandi. Laws of nature, material objects and contingent circumstances.* (by Enrico Pasini, *Università di Torino*)

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II. Introduction.

Rodolfo Garau and Pietro Daniel Omodeo[1]

In a famous inaugural speech delivered at the University of Zürich on 9 December 1922, *What is a natural law?,*[2] Erwin Schrödinger pointed out the difficulty that the pioneers of quantum physics encountered in their attempt to introduce a non-deterministic conception of physical laws. Schrödinger defended a vision according to which natural regularities are the statistic result of particle interactions occurring by chance. Hence, the idea that nature is determined by necessity appeared to him as a sort of long-lived philosophical prejudice which was no longer supported by the most recent scientific advancements, and which he thus intended to put into question. In his view, the strength behind the understanding of the physical world as absolutely necessitated stemmed from the authority of a millenary philosophical tradition:

> From where does the general, widespread belief in the absolute causal determinacy of molecular events and the conviction of the *unthinkability* of the contrary originate? Indeed, from the inherited millenary *habit to think causally,* which makes an undetermined event, an absolute, *primary* accident, appear as perfect nonsense to us.[3]

The conception of nature that he questioned was the Laplacean idea that perfect knowledge of the laws of nature and of the present conditions of a physical system allows one to predict its future developments with certainty. As he stated in a conference held in Berlin in 1931:

> Until about one and a half decades ago, nobody doubted that. Absolute determinism was, so to say, the foundational dogma of classic physics. The clear example to which one oriented himself was classical mechanics: given a system of mass points, their mass, place, and speed in an initial moment, and given the force laws, through which they interact, their movements can be calculated for all future times. This theory found its brilliant confirmation in its application to the celestial bodies.[4]

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[2] Schrödinger (1929).

[3] Ibid., 11: "Woher stammt nun der allgemein verbreitete Glaube an die absolute, kausale Determiniertheit des molekularen Geschehens und die Überzeugung von der *Undenkbarkeit* des Gegenteils? Einfach aus der von Jahrtausenden ererbten *Gewohnheit, kausal zu denken,* die uns ein undeterminiertes Geschehen, einen absoluten, *primären* Zufall als einen vollkommenen Nonsens, als *logisch* unsinnig erscheinen läßt."

[4] Schrödinger (1932), 2: "Bis vor etwa 1 ½ Jahrzehnten hatte man daran nie gezweifelt. Der absolute Determinismus ist sozusagen das Grunddogma der klassischen Physik gewesen. Das durchsichtigste Beispiel, an dem man sich dabei orientiert hatte, war die klassische Mechanik: gegeben ein System von Massenpunkten, ihre Massen, Orte und Geschwindigkeiten in einem Anfangszeitpunkt, gegeben die Kraftgesetzte, wonach sie aufeinander einwirken. Dann läßt sich ihre Bewegung für alle künftige Zeiten vorausberechnen. In der Anwendung auf die Himmelskörper hatte diese Theorie ihre glänzende Bestätigung gefunden."

Schrödinger argued that the resistance encountered by his not-deterministic understanding of physics derived from a belief (even faith, "Glaube") that originated in the historical connection between *mechanics* and *mechanism* – that is, the conception of nature inaugurated in the seventeenth century by philosophers such as Descartes, Gassendi, and Hobbes, which yielded a vision of natural phenomena as the result of necessary kinetic interactions between particles. Such encounter, while providing fertile terrain for the rise Newtonian mechanics, had instilled an unshakable certainty in the absolute necessity of natural phenomena.

Schödinger may have been right in describing the origin of the resistance of the early 20th century academic world against his understanding of quantum mechanics. Nonetheless, our aim in the present volume is to argue that he was *less* accurate when he argued that before quantum mechanics the very idea of science at large was inextricably intertwined with that of necessary determinism, and that this *logical* linkage coincided with *causal thought* tout court. Schödinger was certainly not alone in claiming such a thing. Alexandre Koyré, while characterizing early modern science as a passage from approximation to exactitude, employed the idea of causal determinism and mathematical certainty as a yardstick for scientificity in general, although he also emphasized how it was slowly established and only emerged with difficulty from the natural debates of the Renaissance. Similarly, Anneliese Maier saw the idea of physical determinism as the *via magistra* from medieval to modern science; with this in mind, her studies on the forerunners of Galileo aimed to rehabilitate medieval thought from the suspicion of being far removed from the scientific outlook. In his 1950 classic work on the history of science – tellingly entitled *The Mechanization of the World Picture*[5] – Eduard Jan Dijksterhuis presented mechanism, that is, the encounter of mathematical physics and material determinism, as the leitmotiv and *telos* of scientific advance "from Pythagoras to Newton."

This volume intends to problematize the idea that early modern science, at its origins, was invariably characterized by such a strong commitment to an understanding of nature as determined by necessity, and, as a consequence, the understanding of science as invariably bearing a deterministic vision of nature. In-depth studies on the Aristotelian legacy in Galileo's and Descartes's physics have shown the philosophical continuity underlying the passage from medieval Aristotelian science to pre-classical mechanics.[6] Drawing on these insights, we propose that, at the threshold of the "Scientific Revolution," the empirical and mathematical sciences, as well as the philosophical reflections upon them, were not embedded in a vision of nature which was rigidly determined by necessity. Instead, such a vision emerged, slowly and contradictorily, from an understanding of nature as the "realm of

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[5] Dijksterhuis (1950).

[6] See Damerow et al., (2004); and Renn et al., (2001): 29-149. See also Omodeo and Renn (2015).

contingency." This can be described as form of "diminished or conditional necessity," which characterized late-Scholastic and Renaissance natural philosophies at large.

Our second proposal, which is closely related to the first, is that, during this passage to a necessary vision of nature, contingency turned into a theoretical problem, which questioned and challenged the limits of the theories held by early modern inquirers. In this sense, contingency slowly began to be seen no longer as an intrinsic characteristic of natural phenomena, but rather as a limit of the theoretical frames that scientists and inquirers applied to the study of nature. Through this suggestion, we also mean to question a static and atemporal understanding of epistemological categories. Indeed we argue that there is something fundamentally different in the way an Aristotelian natural philosopher defined a wonder or a monstrous birth as 'contingent', a modern scientist defines the unexpected result of an experiment, and a quantum physicist the behavior of a photon.[7] Although to each inquirer these instances appeared self-evidently contingent, by this they meant very different things. Here we are not going to present necessity and contingency as immutable epistemological categories that constitute *unchangable* presuppositions for all scientific accounts of nature. Rather, we consider these epistemological categories as "historical a priori" – that is, ones that represent preconditions of knowledge as a priori and self-evident, though historically situated and therefore changeable over time – we consider necessity and contingency as historical categories resulting from the combination of various intellectual elements – epistemological, philosophical, material, as well as theological and broadly speaking intellectual.[8]

§1. Ontological contingency.

We have named this first kind of contingency – that is, the one that appeared to characterize late-Scholastic and Renaissance natural philosophies – "ontological," as it appears to have implied that contingency is an intrinsic characteristic of nature. With this, however, we do not intend to equate contingency to chance, nor to propose that it was a per se alternative to an understanding of nature as regulated by laws.[9] In fact, early modern visions of the world generally excluded an idea of nature ruled by chance. Such rebuttal of mere chance – often identified with Epicurean τύχη and Lucretian *casus* – was also motivated by the strong theological backbone that informed early-modern natural philosophy. Nothing could be more extraneous to the widespread trust in God's Providence permeating his Creation than Schrödinger's comparison of the kinetic behavior of gas to a game of

[7] On how the wondrous loomed large over early modern science, see Daston and Park (1998).
[8] On the idea of historical a priori, see Daston, (2008); Feest and Sturm (2011); Daston and Galison (2007).
[9] For an account of the development of the concept of natural laws in the early modern period, see Daston and Stolleis (2009).

dice,[10] which rather resembles the Epicurean doctrine of *clinamen*, which horrified most early modern inquirers. Neither Giordano Bruno's ontological reappraisal of Lucretian physics nor Pierre Gassendi's sober atoms-and-void matter theory excluded a superimposed, providential order of nature. Rather, it was precisely the tension between the belief in the existence of an order bestowed by God upon nature and the observable lack of absolute regularity of natural phenomena, together with the influence of the Aristotelian conception of physical sciences, that prompted reflections on contingency both at the ontological and theoretical levels.

The Scholastic attribution of contingency to the realm of sublunary nature heavily relied on Aristotle's division of the sciences into necessary ones, such as the geometrical and mathematical sciences, and those characterized by regularity, but not necessity ("for the most part".) In brief, this latter category encapsulated all knowledge applying to sublunary phenomena, such as the part of physics dealing with the terrestrial realm, and medicine. The watershed between these two kinds of sciences was identified in the presence of accident and chance, which, for Aristotle, fell into the domain of unaccountability. Aristotle determined that the reason why necessity does not dominate the sublunary world as it does with the celestial one was because of their different material composition, so that the matter characterizing our world, "capable of being otherwise than as it for the most part is, is the cause of the accidental."[11] In this way, the epistemological boundaries of science came to be identified with the ontological limits of the unpredictability of the behavior of material things.[12]

Crucial to this description of chance is Aristotle's notion of final causation. Since Aristotle claims that all phenomena and events have a certain cause or originate from a set of causes, chance can only follow if we attend to the final cause that the object or agent was likely pursuing. In other words, it is

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[10] Schrödinger (1932), 14: "[man denkt sich], daß beim Zusammenstoß zweier Moleküle nicht durch die bekannten Stoßgesetze, sondern durch ein passendes Würfelspiel die weitere Bahn der Moleküle bestimmt wird." "[One imagines], that the collision of two molecules determines the further course of the molecules not by the known laws of collision, but by a suitable dice game".

[11] Aristotle (2014), 1621: "Since, among things which are, some are always in the same state and are of necessity (nor necessity in the sense of compulsion but that which means the impossibility of being otherwise), and some are not of necessity nor always, but for the most part, this is the principle and this the cause of the existence of the accidental; or that which is neither always nor for the most part, we call accidental […] Therefore, since not all things are or come to be of necessity and always, but the majority of things are for the most part, the accidental must exist" (*Metaphysics* E 1026b27-1027a28).

[12] See also ibid., 1622: "But while what is for the most part exists, can nothing be said to be always, or are there eternal things? This must be considered later, but that there is no science of the accidental is obvious; for all science is either of that which is always or of that which is for the most part. For how else is one to learn or to teach another? The thing must be determined as occurring either always or for the most part, e.g. that honey-water is useful for a patient in a fever is true for the most part. But one will not be able to state when that which is contrary to this happens, e.g. 'on the day of new moon'; for then it will be so on the day of new moon either always or for the most part; but the accidental is contrary to this. We have stated, then, what the accidental is and from what cause it arises, and that there is no science which deals with it" (1027a15-1027a27).

only if we know the intended outcome or supposed end of the action or activity of a certain agent or thing that we can evaluate whether they have or have not deviated from it. In *Physics* II, after expounding the difference between nature as art and as causal powers, Aristotle claims that chance and spontaneity ("τύχη καὶ αὐτόματον") must also be listed among the causes that are present in nature.[13] His statement was meant to oppose those who either ruled out chance from nature, or attributed the origin of the universe to it: "[…] there is a third class of events besides these two – events which all say are by chance – it is plain that there is such a thing as chance and spontaneity; for we know that things of this kind are due to chance and that things due to chance are of this kind."[14] However, while "[…] results from chance are appropriate to agents that are capable of good fortune and of action generally," and "therefore necessarily chance is in the sphere of actions (197b1-197b13),"[15]

> [t]he spontaneous on the other hand is found both in the beasts and in many inanimate objects. We say, for example, that the horse came spontaneously, because, though his coming saved him, he did not come for the sake of safety. Again, the tripod fell spontaneously, because, though it stood on its feet so as to serve for a seat, it did not fall so as to serve for a seat. (197b14-197b17).[16]

The spontaneous activity of natural things, Aristotle clarifies, is to be seen as intrinsically opposed to nature not only in respect to the end but also to the cause. Indeed, while the cause of the natural activity of objects is internal (which means, it depends on the form or nature of the thing), spontaneous activity is produced by external causes.[17] Crucial to this description is Aristotle's notion of impediment (ἐμπόδισμα), which would go on to constitute an important trait of the late-Scholastic characterization of contingency. Aristotle believes that the motion of natural things is characterized by their principle or ἀρχή. While most of these motions reach their natural end, others are impeded by extrinsic factors from doing so.[18] In this framework, while physical phenomena are mostly regular, irregularities can otherwise often occur, or, as Aristotle puts it, "[i]n natural products the sequence is invariable, if there is no impediment."[19]

[13] See Aristotle (1984), 334: "But chance and spontaneity are also reckoned among causes: many things are said both to be and to come to be as a result of chance and spontaneity. We must inquire therefore in what manner chance and spontaneity are present among the causes enumerated, and whether they are the same or different, and generally what chance and spontaneity are" (*Physics*, II, 195b31-195b36).
[14] Ibid., 334-335, (196b10-196b17).
[15] Ibid., 337.
[16] Ibid.
[17] Ibid., 338: "The difference between spontaneity and what results by chance is greatest in things that come to be by nature; for when anything comes to be contrary to nature, we do not say that it came to be by chance, but by spontaneity. Yet strictly this too is different from the spontaneous proper; for the cause of the latter is external, that of the former internal" (197b18-197b36).
[18] Ibid., 340: "[...] those things are natural which, by a continuous movement originated from an internal principle, arrive at some end: the same end is not reached from every principle; nor any chance end, but always the tendency in each is towards the same end, if there is no impediment" (199b14-199b18).
[19] Ibid.

Aristotle's "last pagan commentator", Alexander of Aphrodisia, forcefully affirmed the link between Aristotelian philosophy and natural contingency in *On Fate* ("Περὶ εἱμαρμένης"). In this work, which loomed large over medieval and modern philosophical debates, Alexander rejected the Stoic equation of nature and fate. According to him, this equation was based on a false deduction of the existence of natural necessity from the observation of natural regularities, such as celestial bodies and the transmission of specific characters through reproduction. Necessity, in fact, relates solely to laws in their universality but not to individual instantiations, as is seen in the generation of monsters, corruption and disease. As a consequence,

> …something always occurs in the same and constant manner if it belongs to those [phenomena] that occur according to nature, following an underlying law which they evidently respect in a determinate manner. Yet, among natural beings some others occur against nature; moreover, not all [existing things] are according to nature, as is the case with the works of art. Thus, next to the things descending from Fate are others that occur against Fate. Since that which occurs against nature exists, it is not idle to affirm that we should concede the existence of that which occurs against Fate next to that which descends from Fate. We should reasonably say that the nature of every thing is its own principle and the cause of the disposition of all things is that from which they occur according to nature.[20]

The last sentence of this passage reveals a crucial implication of the understanding of contingency inspired by Aristotle's philosophy. If there are phenomena in nature that happen just by chance (and are therefore impossible to account for), and if making science means to investigate regularities, it follows that, when we are dealing with phenomena that are prone to display irregular behaviours (such as those occurring in the sublunary world), we shall focus on their internal elements of necessary causality to account for them – that is, on their essence or forms. As a consequence, contingency is not understood as a limitation of the epistemological framework that we apply to nature, but rather as an intrinsic characteristic of nature. Though contingent phenomena have causes, they lie outside of what can be scientifically stated because of their intrinsic property of being contingent, and not because of an inadequacy of our method.[21] As argued by Anneliese Maier in her *Die Vorläufer Galileis im 14. Jahrhundert* (1949), Scholastic natural philosophers generally maintained that natural agents (in contrast with free agents or "agentes ob intellectu") were "causae determinatae", that is, determined to act necessarily by their forms towards a certain end.[22] Therefore,

[20] Alexander of Aphrodisia (1658): "Unde et illud sequitur, quod eorum quae natura sunt, secundum legem aliquam praeviam, quae de iis determinate ferri videtur, unumquodque semper et constanter fiat. Cum vero inter ea quae natura fiunt, alia etiam praeter naturam fiant, et non omnia secundum naturam (eodem modo quo in Artis operibus fieri videmus) sequitur ut et inter ea quae Fato fiunt locum etiam habeant ea quae praeter Fatum fiunt. Adeo ut, si locum habeat id quod praeter naturam est, nec sit illud inane prorsus nomen, inter ea etiam quae fato fiunt, illi, quod est prater Fatum, locus concedendus sit. Nec igitur a ratione alienum est si dicamus propriam cuiusque rei naturam, eius principium esse, causamque dispositionis omnium, quae ab ea secundum naturam fiunt." [Emphasis added]

[21] For a discussion of the issue of contingency and necessity in medieval philosophy and its theological implication, see Roques, chapter 3 of this volume.

[22] Maier (1949), 222-223: "Jede anorganische Ursache, jedes 'agens a natura' wirkt nach Aristoteles mit Notwendigkeit, d.h. immer und immer in derselben Weisen, ein agens libere (ein agens ab intellectu) dagegen mit Kontingenz derart, dass

all natural phenomena were seen as necessitated according to their formal determination. However, at the same time, natural agents could be seen as contingent in another way, that is, according to the effective actualization of their formal determination. To give an example, a stone is necessarily determined by its form to fall towards the center of the earth which is at the same time the center of the world. This determination cannot be seen as contingent to any extent. However, accidental circumstances may well impede this action from taking place. Therefore, even if its formal determination is necessary, the actualization of this determination remains contingent. As Maier effectively summarizes,

> [i]n addition to this contingency of freedom, scholasticism has a second idea of contingency, namely, that concerning natural events. This is not the modality of the *agere* on the side of the cause, but the modality of the *fieri* on the side of the effect. For though every act of a natural agent works with necessity, the effect does not always occur with necessity, but can be somehow thwarted by other causes or by the lack of disposition in the patiens or otherwise. In this case one speaks of "contingent" events, whereby the word contingency no longer denotes the undeterminateness of the action, but the uncertainty in the realization of the effect.[23]

In Scholasticism (and in general, pre-modern natural philosophy), this latter form of contingency was commonly defined as "contingentia ut plurimum." According to this conceptualization, contingentia ut plurimum (that is, contingency for what concerns things happening for the most part) characterized phenomena of the sublunary world in that they can be impeded by external constraints from carrying out their natural activity to completion. One can trace back an influential example of such a conceptualization of contingency in Scholasticism to Thomas Aquinas's commentary on Aristotle's *Physics*. Here, Aquinas characterizes contingent phenomena as those that can be impeded, in contrast with necessary ones, which cannot be impeded at all.[24] Such a formulation, as often

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es unter gleichen Bedingungen einen Effekt hervorbringen oder nicht hervorbringen kann. Es ist das ein fundamentaler Unterschied swichen den beiden Gruppen von wirkenden Kräften, die die Scholastik unterscheidet: die einen sind causae determinatae, die mit mechanischer Notwendigkeit auf ein bestimmes Ziel hinwirken und immer wirken (oer wenigstens immer zu wirken bestebt sind), während die andern causae intederminatae sind, die ceteris paribus mit einer 'contingentia ad utrumlibet' wirken oder nicht wirken können."

[23] Ibid., 223: "[…] neben dieser Kontingenz der Freiheit gibt es für die Scholastik noch eine zweite, nämlich eine Kontingenz der natürliche Ereignisse. Bei dieser handelt es sich nicht um die Modalität des agere auf Seiten des Ursache, sondern um die Modalität des fieri auf Seiten des Effekts. Denn obwohl jedes agens naturale mit Notwendigkeit wirkt, tritt der Effekt nicht immer mit Notwendigkeit ein, sondern kann per accidens durch andere Ursachen oder durch die mangelnde Disposition im patiens oder sonst irgendwie vereitelt werden. In diesem Fall spricht man von "kontingenten" Ereignissen, wobei das Wort Kontingenz nicht mehr die Undeterminiertheit des Wirkens, sondern die Unsicherheit im Zustandekommen der Wirkung bezeichnet. Der Gegensatz zu dieser Kontingenz ist die Modalität derjenigen Effekte, due schlechtin immer und unvermeidlich eintreten, wenn die sie anstrebenden Ursachen gegeben ist."

[24] Aquinas: "Sciendum etiam quod quidam definierunt esse necessarium, quod non habet impedimentum; contingens vero sicut frequenter, quod potest impediri in paucioribus. Sed hoc irrationabile est. Necessarium enim dicitur, quod in sui natura habet quod non possit non esse: contingens autem ut frequenter, quod possit non esse. Hoc autem quod est habere impedimentum vel non habere, est contingens. Natura enim non parat impedimentum ei quod non potest non esse; quia esset superfluum." "[…] someone defines to be necessary what does not have any obstruction; and also contingent for what concerns things that happen for most part as what can be impeded on few occasions. But this is not correct. Indeed, they say necessary is defined as what by nature cannot not be; contingent or for the most part, what can not be. Rather, what can have or not have impediment is contingent. Nature indeed does not dispose an impediment for what cannot not

happens, was codified and reported by scholastic manuals (as for instance by Rudolph Goclenius' 1613 *Lexicon Philosophicum*[25] and by Johannes Micraelius' 1653 homonymous work[26]) at least until the mid-sixteenth century. Examples of this conceptualization found their place not only in physics, but also in "biological" and medical studies. In these domains, the emergence of irregularities—such as monstruous births—was often understood as deriving from the departure from teleological determination due to the resistance of matter.[27]

§2. Renaissance Paths to Natural and Epistemological Contingency

Contingency also held a fundamental role in the science and gnosiology of the Renaissance. Already in the fifteenth century, important reflections on the character of human knowledge and of nature, such as those from Nicholas of Cusa, anticipated the profound revision of the understanding of contingency that marked the Renaissance period at large.[28] In this context, an element of novelty was introduced through the rise of the social and cultural status of the practical arts. This determined, among other things, an increasing interest in experiential knowledge, which is by definition intrinsically fluid and apparently lacks strict necessity. Accounting for this contingent aspect of practice represented a challenge that invested the practitioners with a theoretical predisposition and gave the learned scholars practical interests. More broadly, the category of contingency, applied to epistemology as well as to ontology, allowed both groups to reconceptualize the relation between experience and theory. A telling example can be found in Renaissance mechanics, whose mathematical formalization started precisely in this period and largely arose as a consequence of the growing interest in the practical arts. Renaissance scholars who engaged with mechanics generally agreed on the inevitability, as well as desirability, of including a codification of material vagaries in their theories. Material bodies, they assumed, rebel against formal cogency, that is to say, they can be described mathematically as they imply a certain regularity but do not entail perfect exactitude.

be, for this would be superfluous" Commentaria in libros physicorum," in *Corpus thomisticum*, electronic edition (http://www.corpusthomisticum.org), lib. 2 l. 8 n. 4. [...]-2

25 Micraelius (1653), 277: "*Contingens ut plurimum*, est quod fit natura, cui quandoque ponitur impedimentum", that is, "Contingent for the most part is what happens in nature, whenever an impediment is given."

26 Goclenius (1613), 464 : "Modi, quo Continges aliquid dicitur, tres sunt: Unus, quo dicitur quid evenire plerunque [sic] seu ut plurimum: Alter, quo pro re nata: Tertius, quo raro, ut fortuna. Primi Modi contingentia per se causas habent, & sunt *epistemata*, cum sint eorum rationes universales, ut necessariorum, quibus sunt vicina. Secundi et Tertii modi contingentia non habent causas necessarias, sed accidentalis. Itaq; non sunt *epistemata*. Horum (secundi & tertii modi) causae dicuntur indefinitae, quia effecta possunt efficere, vel non efficere, ita ut incerta sint. Ac Aliae sunt liberae, aliae fortuitae, & casuales." "There are three ways in which something is said to be contingent. First, of what is said to happen for the most part; second, according to circumstances; third, and more rarely, by chance. The contingent things of the first kind have per se causes, and are sciences, because their properties are universal as those of things said to happen by necessity, to which are similar. […]"

27 See Manzo in this volume.

28 We consider Cusanus from this viewpoint in Garau and Omodeo (forthcoming).

However, contingency not only represented an unavoidable trait of mechanics understood as an art: it also permeated its theoretical tools. For instance, the scholastic concept of "necessitas secundum quid", which originally referred to the ontological impossibility of absolute necessity in the created world, was transplanted from theology and applied to the progressively mathematized field of physics. Theologically, the notion of *secundum quid* referred to the limitation (*quid*) imposed by the vices upon the perfect realisation of a virtuous life; whereas, in the field of statics, *secundum quid* referred to the mechanical constraits that limited, and also channeled, the perfect realisation of natural tendencies. Scholars such as Cardano, Niccolò Targaglia and Giovanni Battista Benedetti operationalized this "marker" of ontological contingency in their Archimedean reworking of the *scientia de ponderibus* – the medieval science of weights from Johannes de Nemore. Their reflections on circular motion as mechanically impeded straightforward motion were developed along a line of thought that ascribed a natural character to rectilinear motion and a violent one to circular motion. The relation of the necessary law prescribing natural linearity of motion to material bodies with the contingent reality of effective circular motion prepared Galilean proto-inertial views and Cartesian inertia.[29] At a philosophical level, the recognition of the importance of contingency in mechanical disciplines brought about important original epistemological reflections. One example is how the polymath Girolamo Cardano emphasized the relevance of both the theoretical and the experiential components of arts such as mechanics and medicine – to mention only the two disciplines he most valued and contributed to developing. He claimed that the practice of these disciplines not only presupposed a deep understanding of their theoretical aspects (as for instance the geometrical and the mathematical proportions that ruled over machinery and theory and exact quantity in medicine). Rather, when it came to the arts, the *particular* and the *contingent* also mattered. Therefore, a skillful practitioner should rely on theory as much as on experience, for while the former is marked by the necessity of its principles and demonstrations, the latter must cope with material contingencies. Within this perspective one can understand the statement of the military engineer Bonaiuto Lorini on fortifications:

> [T]hose who wish to deal with these works do not only need to know mathematics, in order to assess and realize them, but also have to be prudent and experienced mechanics. (Lorini 1596, 172)[30]

In astronomy, another field of natural inquiry investigated by mathematical means, the issue of contingency and necessity also held an important role during the Renaissance. An example of this

[29] This is the subject of Omodeo, chap. 5.
[30] "Adunque per le cose dette, ricorderò a quelli che si vorranno porre a così fatte imprese nel giudicare, overo comandare la essecutione, di qualsivoglia machina, essersi necessario non solo havere cognitione delle matematiche, ma ancora essere avveduto, e pratico mecanico".

can be seen in Copernicus' cosmology, as presented in the first book of *De revolutionibus orbium coelestium* (1543). His view did not imply a strict form of necessitarism. Instead of presenting an extensive treatment of material and efficient causes, Copernicus focused on formal and teleological necessity. He took the sphere as a model of supreme final and formal causation. The elements can be reduced to their essential activities as they must coalesce into relatively perfect spheres. Their only 'natural' motion must be that of the sphere, that is, a circular revolution. Thus, by focusing on the world's overall geometry, Copernicus marginalized the physical issue of the material causation of motion and focused on its formal and final necessities. Although his admirers found some elements of a physical theory in *Book One* of *De revolutionibus*—demonstrating Copernicus's openness to a reform of physics—, he remained noncommittal on the material and efficient causes that bothered his followers. Many among them – most prominently Giordano Bruno, William Gilbert, and Johannes Kepler – developed vitalistic explanations of animal-like planetary motions through the heavens, which reintroduced contingency in the realm of cosmology. In fact, the thesis of the plurality of worlds, which many understood as corollary to Copernicus's vision of a planetary Earth, suggested that terrestrial contingencies can be found in other planet's landscapes, even though our eye cannot detect them from a distance. However, it was not Copernicus's task but that of his readers and followers to face the problem of contingency descending from the principle of cosmological homogeneity.[31]

Contingency concerned the practical and astrological pendant of theoretical astronomy, the so-called *astronomia practica*, more directly. The art's practitioners never questioned astrology's inherent contingency – that of a conjectural art dealing with natural and human contingency – although the precise scope and meaning of this contingency was a matter of debate. In the Latin world, the passage from late-medieval to early-modern astrology was marked by a shift in the dominant interpretations of celestial influences. Medieval astrology was essentially an 'art of embodiment', in which anagogy and self-governance were considered fundamental while any uncertainty of the prognostics was accepted as inherent to the material world. Much of this relaxed attitude toward contingency changed during the sixteenth century, in no small part due to a new skepticism about astrology and the very reality of celestial influence. Cardano's false prediction of the longevity of Edward VI of England provoked heated criticisms. In Melanchthonian Germany, astrology continued to flourish. Protestant practitioners of this art shifted their focus from the medieval concern with the bodily dimension of astral influences to a sort of praxeology, which aimed to maximize the material and spiritual profits descending from celestial governance over terrestrial vicissitudes, and to minimize losses. Shifting priorities of astrological prediction also shaped attitudes towards

[31] See Regier, Chap. 6.

contingency. In particular, whereas ontological contingency was at the center of late-medieval body-oriented astrology, sixteenth-century astrological conjecture became an epistemological phenomenon that was often seen as accidental to the art.[32]

§3. Epistemological contingency.

We propose that it was during the seventeenth century, and with the establishment of early modern mechanism, that contingency lost the ontological understanding by which it was largely characterized in the Renaissance and progressively gained a prevailing epistemological meaning. We have named this second kind of contingency "epistemological contingency." Here, we argue, contingency concerned a reflection on the limits of scientific methodology and learning practices. Since nature was increasingly portrayed as characterized by absolute necessity, phenomena that escaped the epistemological power of theoretical frameworks, systems of laws, or learning practices, pointed to their expansion, even revision, or to a probabilistic approach to knowledge in general. This transformation is well exemplified, in more general philosophical terms, by Spinoza's famous statement in *Ethics* 1, 29 that "[i]n nature there is nothing contingent, but all things have been determined from the necessity of the divine nature to exist and produce an effect in a certain way,"[33] while in 1, 33 he defined contingency as a *determined* possibility which is only undetermined *for us*, as "[…] a thing is called contingent only because of a defect of our knowledge."[34]

In our view, this passage happened slowly and ambiguously. As the essays collected in this volume show, prominent figures of early modern mechanism, such as Descartes, were still ambivalent in portraying contingency as an intrinsic element of the natural world and as an epistemological limit to our understanding of this world. Francis Bacon is a further example of this ambivalence. Bacon, who was writing at the threshold of the seventeenth century and whose work was a bridge between Renaissance philosophy and modern empiricism, continued to allot a crucial ontological relevance to contingency. His idea of the *advancement of learning* was closely connected to the benefit that knowledge can bring to humanity, in particular practical knowledge and applications. In this perspective, he most valued the possibility to *manipulate matter and its appetites* for the benefit of human life. The artist's imitation of nature, he maintained, is enabled by the possibility of making natural entities deviate from their natural course. In other words, the possibility to direct nature depends on its intrinsic contingency, as revealed by preternatural generation. In line with Renaissance conceptions of contingency as originating from materiality, he wrote in crude terms in *De augmentis*

[32] Vanden Broecke, Chap. 6.
[33] Spinoza (1985), 433.
[34] Ibid., 436.

scientiarum (1623) that nature "is driven out of her ordinary course by the perverseness, insolence, and forwardness of matter and the violence of impediments."[35] One of the contributions to this volume shows how, on the one hand, Bacon was anchored to the idea of contingency as an intrinsic and ontological trait of natural phenomena, through which he provides a very different explanation than the one provided by scholastic-Aristotelianism. On the other, his focus on the notion of "pretergeneration" (that is, nature's spontaneous generation of monsters and errors), functional to his philosophical agenda aimed at mastering nature through art, represents a strong detachment from the Aristotelian idea that science only concerns phenomena happening necessarily for the most part. Protogeneration is understood by Bacon as a result of the Fall: "Matter, as well as humans, started to behave in such a way as to follow not only the general good, but also the individual one. It is this particular feature that renders possible the deviations from the usual course of nature."[36] Interestingly, Bacon does not see a direct contradiction between the idea of the existence of eternal laws of nature, imposed by God at the moment of the creation, and the fact that matter, either through pretergeneration or manipulation, can eventually deviate from such laws. Indeed, Bacon identifies the Fall as the moment when the possibility for "alternative things," that is, contingent deviation from the laws of nature, can take place. As a result, matter can be "seduced" – that is, driven away by the course it would otherwise follow through human manipulation – in order to create new objects. At the same time, external conditions can determine spontaneous deviations from the natural course. Therefore contingency, in this view, is seen as both the result of human manipulation as well as an inner character of nature.

At some point in the seventeenth century, however, such a shift to a necessary understanding of nature eventually determined, in turn, an epistemological shift in the understanding of contingency. Truly, this did not happen homogeneously across all disciplines. For instance, the early modern attempts to make medicine—a science that perhaps more than any other has to cope with all sorts of contingencies—a science and not only a "techne" tended to erase the Galenic model of treating of irregularities by anchoring them to a system of gerarchically interconnected laws, and to refer them to the experience and the eye of the expert physician.[37] Physics, on the contrary, took decisively this direction. In a broad sense, seventeenth-century mechanical philosophy, understanding all phenomena as the result of microscopic bodies in motion, carried with itself both ideas that all phenomena follow necessarily from the reciprocal action of microscopic corpuscles, and that, at the same time, the complexity and non-observability of such interactions largely prevented a full

[35] Bacon (2011), 294. See Rusu, Chap. 9.
[36] Rusu, Chap. 9.
[37] See Dyde Chap. 13.

accountability of all possible way in which such particles were determined to behave. Since mechanical philosophy became largely the shared background of scientists, this way of understanding contingency was common not only to many "Cartesian" rationalistic thinkers, but also to empirical and experimental inquirers. For instance, as early as 1686, in *A Free Enquiry into the Vulgarly Received Notion of Nature,* the experimental inquirer Robert Boyle suggested that the apparent irregularities that we observe in nature are due to our limited power of understanding the providential design of God and the order he imposed on nature.[38] In the philosophical framework he established, apparent "aberrations" or "irregularities" were likely; he intimated they were the result of our impossibility to refer to them to their "genuine causes":

> […] I think it very possible that an artificer of so vast a comprehension and so piercing a sight as is the maker of the world might, in this great automaton of his, have so ordered things that divers of them may appear to us, and as it were break out abruptly and unexpectedly, and at great distances of time or place from one another, and on such accounts be thought irregular; which yet really have, both in his preordination and in the connection of their genuine causes, a reference that would, if we discerned it, keep us from imputing it either to chance or to nature's aberrations.[39]

Picking up the image of nature as a mechanical clock (one can perhaps recall the famous verses of Voltaire's, "*L'univers m'embarrasse, et je ne puis songer/ Que cette horloge existe et n'ait pas d'horloger*")[40], Boyle claimed that if Jesuit missionaries presented a clock to a Chinese king, and its alarm was set to a particular time of the day, the king would think that the alarm was likely due to a disorder in its mechanism. However, he would have recognized its regularity had the clock been set to chime each hour:

> let us consider that if, when the Jesuits that first came into China presented a curious striking watch to the king, he that looked to it had wound up the alarm so as to strike a little after one; if (I say) this had been done, and that these Chinese that looked upon it as a living creature or some European animal, would think that when the index pointing at two of the clock likewise struck the same hour, and so three, four and onward, they would judge that these noises were regularly produced, because they (at equal intervals of time) heard them, and whensoever the index pointed at an hour, and never but then. But when the alarm came unexpectedly to make a loud, confused and more lasting noise, they could scarce avoid thinking that the animal was sick or exceedingly disordered. And yet the alarming noise did as

[38] Boyle (1996), 101: "[…] it seems more allowable to argue a providence from the exquisite structure and symmetry of the mundane bodies, and the apt subordination and train of causes, than to infer from some physical anomalies that things are not framed and administered by a wise author and rector. For the characters and impressions of wisdom that are conspicuous in the curious fabric and orderly train of things can with no probability be referred to blind chance, but must be [ascribed] to a most intelligent and designing agent. Whereas on the other hand, besides that the anomalies we speak of are incomparably fewer than those things which are regular and are produced in an orderly way; besides this, I say, the divine maker of the universe being a most free agent and having an intellect infinitely superior to ours, may in the production of seemingly irregular phenomena have ends unknown to us, which even the anomalies may be very fit to compass."
[39] Ibid.
[40] Voltaire (1772), 9.

> properly flow from the structure of the little engine, and was as much designed by the manager of it, as those sounds of the clock that appeared manifestly regular.[41]

The idea that the apparent irregularities and singular instantiations of nature could be traced back to an underlying regularity and necessity also animated the early modern interest in natural history, which was a fundamental part of the Baconian project. From the point of view of Aristotelian philosophy – in which no science whatsoever can be given of particular things – a collection of particular instantiations, such as natural history appeared to Bacon, was rather seen as a gathering of oddities and curiosities rather than something that could be considered functional to a scientific enterprise. In the preface to Bacon's *Sylva Sylvarum*, Rawley acknowledged that Bacon's natural history might appear like "an indigested heap of Particulars," which might seem "Vulgar and Trivial, mean and sordid, curious and fruitleß," and that previous natural histories were rather "gathreth for delight and use," and full of pleasant Descriptions and Pictures," and "affect and seek after Admiration, Rarities, and Secrets;" but that, however, it was functional to the broader project of "collect[ing] material for the Building" of science.[42] The collection of seemingly contingent natural events, in addition to providing a repertoire of individual instantiations, was meant to make the underlying casual necessity of those events emerge.[43]

Such shift, however, did not take place abruptedly, and opend up new questions and problems. While basing his system on strong intellectualist and deterministic stances (with the exception of the activity of the human soul), in the early exposition of his system of natural philosophy (*Le Monde*, 1632) Descartes still attributed the discrepancy between God's action of recreation and preservation of nature and the actual behaviour of bodies—displayed by the semingly paradoxical derivation of rest and curvilinear motion from the divine determination to rectilinear, indefinite motion—to the resistance of matter, which he appears to identify, wheather consciously or not, with an element of intrinsic contingency in the domain of nature, in a similar fashion to scholastic physics. While such position was then corrected in the *Principles of Philosophy* (1637), this shift displays the slow adaptation of early modern inquirers to the transformation of contingency implied in the adoption of the mechanistic worldview.[44] Descartes' later studies on animal locomotion, on the contrary, though dealing with the throny issues of "freedom" and "spontaneity, display a more coherent shift towards the negation of contingency in the "biological" domain.[45]

[41] Boyle (1996),102–3. See Garau, Chap. 10.
[42] Bacon, (1670), Preface (page number not listed).
[43] On Bacon's understanding of natural history, see Anstey (2012): 11–31.
[44] See Garau chapter. 10.
[45] See Kekedi chapter 12.

The necessity of harmonizing the now predominant idea of natural laws with the apparent irregularity of the behaviour of bodies yet determined by such laws was also a fundamental problem that entailed a new treatment of contingency. Leibniz's investigation on the nature of natural laws (whiche he considered as contingent) and their difference from geometrical (and necessary) laws lead his to claim that physical laws do not supervene but are instead the principles through which physical events and their aggregate effects are engendered. Here final causation is implied by the contingency of natural laws.[46] Hooke attempted to reconcile the idea of necessary laws of nature (derived from early modern mechanism) with the issue of experimental contingency of Baconian derivation. In this frame, a significant shift between Hooke's and the Cartesian and the Galilean approach to the laws of mechanics took place. While Descartes and Galileo saw in the concrete constitution of matter a limitation to the applicability of mechanical laws to real world, and therefore posed mechanical laws in ideal systems where the interaction between bodies was deprived of friction and dissipation, Hooke maintained that mechanics, rather than abstract mathematics, provided the general laws of nature, and believe that such rules can be found and verified through experiments and observations on concrete bodies. This entailed a significant shift from the abstract mathematics of Galileo and Descartes to the concrete elastic bodies that were the subjects of Hooke's experiments.[47] More in general, early modern inquirers were particularly concerned with the impact of often unaccountable material contingency on experimental results, and, given that the impossibility of achieving a full control on experimental conditions, on the disunifornity of in the results of replicated experiments. The two first responses to such problems were based, respectively, on the pre-condition of abstraction, associated with mathematical procedures of control, as for instance in Galileo, and on the large-scale repetition of experiments, as for instance in Boyle, Santorio, and others. These new approaches progressively merged in the course of the eighteent century, with the progressive application of probabilistic devices to the evaluation of experimental contingencies: "[i]n this way, epistemic probability" ended up being connected in a mathematically demonstrative way "to the quantitative evaluation of past knowledge (in the form of series of tests converging on some value of 'probability'), although it is manifest that the measure of the probability of conjectures would be sourced from an *a posteriori* evaluation of contingent circumstances."[48]

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[46] See Tho, chapter 14.
[47] See Sacco chapter 11.
[48] See Pasini, chapter 15.

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