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Klaas Landsman
Ellen van Wolde (Eds.)

THE
CHALLENGE
OF CHANCE

A Multidisciplinary Approach
from Science and
the Humanities

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Klaas Landsman · Ellen van Wolde
Editors

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Klaas Landsman (1963) obtained his Ph.D. in Theoretical High-Energy Physics from the University of Amsterdam in 1989. He was a research fellow at the University of Cambridge from 1989 to 1997, interrupted by an Alexander von Humboldt Fellowship at Hamburg in 1993–1994. He was subsequently a Royal Academy Research Fellow at the University of Amsterdam from 1997 to 2002, and obtained a Pioneer Grant from NWO in 2002. Klaas has held the Chairs in Analysis and subsequently in Mathematical Physics at the Radboud University since 2004, and in 2011 was awarded the Bronze Medal of this university for his outreach work in mathematics. His research is mainly concerned with non-commutative geometry and with the mathematical foundations of quantum theory. The latter topic lies behind his interest in (pure) chance and probability.

Ellen van Wolde (1954) obtained her Ph.D. in Biblical Studies from Radboud University in 1989. She was a professor at the Faculty of Theology of University of Tilburg from 1992 to 2008, and has held the Chairs in Textual Sources of Judaism and Christianity at Radboud University since 2009. In 2005 she was appointed as a member of the KNAW, becoming a member of its Executive Board in 2011. Ellen's research is mainly concerned with the Old Testament Books of Genesis and Job, and with methodological approaches that acknowledge the role culture and language plays in the formation of biblical texts. A related field of interest of hers is the question how chance, bad luck, or coincidence were explained in ancient cultures and religions, especially in so far as these explanations still influence our present views.

Introduction

Klaas Landsman, Ellen van Wolde and Noortje ter Berg

> *Das Gewebe dieser Welt ist aus Notwendigkeit und Zufall gebildet*
> *(The fabric of reality is built from necessity and chance)*
> Goethe

Abstract This chapter introduces the theme of the book (i.e., the challenge of chance) and includes brief surveys of the individual chapters.

The collapse of cohesion is one of the features that characterize chance. By sheer accident, or so it seems, something breaks the typical regularity of the natural world, like a comet disrupting the solar system. At a human scale, we find examples like unexpectedly bumping into an old friend, or losing a loved one in an accident. Such (seemingly) random phenomena appear arbitrary; they disrupt our lives and frustrate our human need for logic and meaning. The ensuing feelings of uncertainty and apprehensiveness, in turn, trigger us to search for explanations that will help restore order and normal patterns of cause and effect. In a word, we are challenged by chance, and we have been so at least since antiquity.

How do we respond to such challenges? For thousands of years people have tried to decide whether chance is a fundamental and irreducible phenomenon, i.e. certain events are not caused—they just happen, or whether chance is merely a reflection of our ignorance. Either way, we find the experience of chance hard to deal with. Humans constantly try to understand random phenomena and prefer explanations that (re)install meaning. The question, then, is whether this search for explanation and meaning has succeeded, or, at least, has a fighting chance (sic) to succeed.

This question is more subtle than it appears, since with his revolutionary claim that the universe is necessarily the way it is and yet has no goal, Spinoza cut the thread connecting explanation and purpose. Even necessity was subsequently

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challenged by Darwin's theory of evolution in the 19th century, followed by quantum theory in the 20th, in both of which chance plays a fundamental role. Insult following injury, from Hume and Kant onwards even the causal patterns that permeate traditional science began to be questioned. From Aristotle to the 18th century, natural philosophy had seen these patterns as real, our role being limited to discovering them. Now, however, causality was claimed to be a mere by-product of our subjective need for rules, patterns, and meaning, which eventually led Bertrand Russell to his witticism that causality is "a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm."

The overall picture was summarized by the chilling words of Physics Nobel Laureate and popular science writer Steven Weinberg: "The more the universe appears comprehensible, the more it also appears pointless." However, he immediately qualified this pessimistic view (quoted from his popular account of the Big Bang entitled *The First Three Minutes*) in the following way: "But if there is no solace in the fruits of our research, there is at least some consolation in the research itself. Men and women are not content to comfort themselves with tales of gods and giants, or to confine their thoughts to the daily affairs of life; they also build telescopes and satellites and accelerators, and sit at their desks for endless hours working out the meaning of the data they gather. The effort to understand the universe is one of the very few things that lifts human life a little above the level of farce, and gives it some of the grace of tragedy."

This effort to understand includes the present book, which complements the excellent interdisciplinary books on chance that have already appeared over the last decades, both at a scholarly[1] and a popular[2] level. By incorporating a wide range of historical and contemporary sciences, the studies presented here allow us to develop a transdisciplinary perspective on chance. Thus our multidisciplinary approach, in which a team of authors explores the issue of chance in the disciplines of philosophy, mathematics, economics, game theory, statistics, physics, theology, neuropsychology, genetics, ecology, history, law, and linguistics, makes us aware of shared insights in these distinct disciplines. Let us first give a short survey of the articles originating in these various disciplines, to conclude with a few thoughts towards a transdisciplinary perspective on chance.

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[1]See, for example, G. Gigerenzer et al. (eds.), *The Empire of Chance* (Cambridge University Press, 1989), L. Krüger et al., *The Probabilistic Revolution*, Vols. 1, 2 (MIT Press, 1990), I. Hacking, *The Taming of Chance* (Cambridge University Press, 1990), I. Hacking, *The Emergence of Probability* (Cambridge University Press, 2nd ed. 2006), S. Kern, *A Cultural History of Causality* (Princeton University Press, 2004), P. Vogt, *Kontingenz und Zufall: eine Ideen- und Begriffgeschichte* (Akademie-Verlag, 2011).

[2]E.g., N.N. Taleb, *Fooled by Randomness* (Penguin, 2004), W. Poundstone, *Fortune's Formula* (HIll and Wang, 2005), K. Mainzer, *Der kreative Zufall* (C.H. Beck, 2007), N. Silver, *The Signal and the Noise: The Art and Science of Prediction* (Penguin, 2012), D. Hand, *The Improbability Principle* (Bantam Press, 2014).

1   Contents of This Book: Addressing the Challenge

The opening chapter by Lüthy and Palmerino presents a survey of 2500 years of linguistic, philosophical, and scientific reflections on chance, coincidence, fortune, randomness, luck and other related concepts. In particular, they show that any concept of chance could only be understood through the alternative that the particular notion of chance attempted to exclude. And precisely because the alternative that was to be excluded did not have a stable identity, also its anti-pole (i.e. the idea of what chance is) had a variable meaning. For example, 'chance' has been opposed to 'fate', 'providence', 'natural laws', 'determinism,' and 'the knowledge of causes'. This heterogeneous list illustrates what a slippery concept 'chance' really is. The endeavour to pin down and define concepts by contrasting with opposites is a thread that runs throughout this book.

Perhaps the most rigorous way to analyse chance is through pure mathematics. In Terwijn's chapter we are told that even the best efforts in the 20th century to capture randomness mathematically have yielded no single 'true' notion of randomness." Instead, a number of (equivalent) definitions have been proposed that contextualize randomness relative to prior notions such as computability. Accordingly, an object is defined as random if its description cannot be shortened in a computable way, that is, randomness is opposed to computable compressibility. For example, according to this definition, despite the completely irregular distribution of its infinitely many digits the number $\pi = 3.14\ldots$ is not random at all, since instead of giving all these digits we could write a short program to compute them. On the other hand, most real numbers are random in this sense, although, curiously, this fact cannot be proven for any given random number.

Historically, the first application of mathematics to chance was to betting and gambling. Unexpectedly, two centuries later similar methods turned out to lie at the heart of game theory in economics (Weitzel and Rosenkranz). In finance, one typically assumes complete rationality on the part of all actors. In combination with the 'efficient market hypothesis', this would naively seem to imply a deterministic course of events. However, one of the remarkable predictions of game theory is that even on these assumptions the most rational strategy is often a random mixture of a number of alternative possibilities. Of course, this again blurs the alleged demarcation between determinism and chance.

Moving from probability to statistics, Goeman describes how researchers in medical statistics and psychology look for statistical correlations between data in the hope of revealing (publishable) evidence of a chain of cause and effect (for example, to conclude or predict that drinking milk is healthy whereas smoking is not). In a word, statistics is used to 'negotiate' chance. However, as Goeman argues, even ignoring notorious (especially Dutch) cases of scientific fraud, estimates of the unreliability of serious and published clinical studies range from 14 to 89 %, and he makes several proposals to improve this situation.

In the next chapter, Landsman's analysis of the 'fine-tuning argument' bridges the gap between chance in mathematics and physics on the one hand and chance in

philosophy and theology on the other. The laws of nature contain parameters that are set at highly specific values for the universe to exist, and for us, humans, to exist in it. The list of possible explanations for this fine-tuning of the universe includes: design by a deity, a 'multi-verse' (so as to increase the probability of the existence of our own universe), 'blind chance', and finally, 'blind necessity'. For Landsman the latter two are the best options but he adds: "The present state of science does not allow us to make such a choice now, and the question even arises whether science will ever be able to make it, except perhaps philosophically."

Contrary to common belief, theological stances from the past were not all deterministic. In the Hebrew Bible, for instance, the book of Job describes the dramatic alternation between fortune and misfortune in a non-deterministic way, as Van Wolde's analysis shows. Job is unaware that God is carrying out an experiment because of a wager with the satan. Job tries to find his own explanations and reasons, but is chastised by God for obscuring "the design by words without knowledge". God's dismissive words reverberate throughout the years of thinking about chance, coincidence, luck, randomness and such concepts. Are these just words without knowledge? Or is it our historical, spatial, and cultural perspective that limits our type of rationality? Van Wolde also discusses this question with respect to the first chapter of the book of Genesis, which for many people, secular or non-secular, is the clearest example of God initiating a cause-driven chain of events. The question, then, is whether this is really the case.

It is a relatively small step from the ancient Near-East to the ancient Greek and Asian worlds. Bringing both philosophical and Buddhist attitudes towards chance into the picture, Thijssen and Loy point out that at first, 'luck' (or 'chance') and 'karma' seem to be opposing concepts. If something happens because of good or bad luck, it is beyond the agent's control whereas, in contrast, karma, implies that agents have a great deal of control (albeit indirect) over what happens. However, both philosophical traditions believe that being invulnerable to bad luck depends upon mental transformation. Western traditions focus more on coping with the emotional effects of bad luck, whereas Eastern traditions concentrate on the agent's motivations. But both aim to change our experience of the world and are still helpful today in our attempts to secure happiness in the face of adversity.

In contrast, the contemporary western approach to chance as an aspect of human life is set in the framework of cognitive neuroscience. van Elk, Friston, and Bekkering discuss the deeply engrained human tendency to give meaning to coincidences. However, it turns out that not only are humans remarkably bad at estimating chances and probabilities, they also tend to perceive a causal nexus between situations even where there is none. In doing so, the original meaning of coincidence is subverted, as it gestures at a perceived connection between events even though we cannot explain the causal mechanism behind it. Following Helmholtz, they argue that the human brain a priori constructs a predictive model of the world, which however may be interrupted or distracted by seemingly random events (neuroscientists typically have a deterministic world picture, so that randomness is never absolute but is only experienced as such). However, it is their

very randomness that endows such events with at least subjective explanatory power, in that the brain may conclude that the inexplicable becomes explicable, precisely because it was random.

Medical research has to bridge another chasm, namely from biology and genetics to the feelings of loss when a handicapped child is born 'by chance' to healthy parents. Brunner shows in his study that random genetic mutations that originate at the molecular level can subsequently have either causal or probabilistic consequences for genes, individuals, species, ecosystems, and eventually even for the planet. The example of genetics also raises the question whether random events are beneficial or harmful: on the one hand, random errors of replication during the formation of germ cells can cause birth defects that result in a miscarriage or severe problems for the child and parents. On the other hand, such mutations drive evolution at the level of the species, typically enabling it to improve.

Coincidence also plays a central role in De Kroon and Jongejans' chapter. They counter the statement that "if it's a coincidence, it is not scientific"—a judgment implied in the premises of the previous two chapters. They argue that if 'chance processes' such as a heavy storm occur at the right place and time they could well determine the development of ecosystems and they claim "chance is pervasive in ecological systems." But what is the status of chance here? Qualifying their thesis, the authors argue that chance events typically have a deterministic origin, and that the stochastic nature of their occurrences can often be defined within a range of predictable variation. What remains problematic is the uneasy relationship between the scale-dependence of cause and effect with that of stochasticity.

In his chapter, Hekster tells us that because coincidences are, by definition, not causally related, traditional historians have tended to ignore them. So when is a coincidence just a coincidence, and when does a pattern occur? And why would a historian be interested in 'accidents', 'singular events', or 'contingent circumstances'? Surely, it has been historically decisive that Hitler survived all attempts to kill him (except his own). Yet it is tempting to walk the path of 'what-if history'. But does counterfactual thinking liberate us from a false sense of historical determinism or does it, instead, lead to a view of history as a series of random events? The answer to this question depends entirely on one's sense of the causal forces active in history. A providentialist or determinist will see inevitabilities and necessities. As Hekster argues, much will also depend on how one defines "the intersection between private actions and the public world," where "history develops." At those intersections, coincidences might play an explanatory role, but only if understood in terms of micro-causes related to individual human agency.

In Jansen's article, which deals with 'accidental harm' under Roman law (which has exerted a paramount influence on modern European Law), we once more encounter the Latin word 'casus' with its many meanings, which signifies not just 'accident', but also 'misfortune', 'fate', 'adversity' or 'setback,' which, in the legal context, all amount "to an event resulting in damage which cannot be traced back to another party's fault." For the Roman lawyer, however, 'casus' is not opposed to necessity, but to some state of intentionality. In any case, accidents are seen as purely negative, and the question is simply who is liable for the damage they cause.

Yet at least in Western Europe, after WW II this principle was increasingly countered by the tendency of governments to protect citizens from misfortune, notably by means of a social security system—"from womb to tomb" (Churchill). In recent years such systems seem to be weakening, partly for financial reasons (they are arguably becoming unaffordable), but also under the influence of liberal tendencies to restore the individual's responsibility for whatever happens to him or her.

The chapter by Van Hout and Muysken starts with a rejection of complete generative models of linguistics à la Chomsky, in which chance hardly plays any role and at best represents a lack of knowledge. Instead, they use numerous examples to show that chance, in the sense of language variation, plays a major role at each of the four levels of linguistics: inter-species variability, inter-language variability, variability in the linguistic signal within a given language, and finally inter-individual variability. In each of these four levels, the notion of chance figures as an inherent property; it is a probability mechanism to explain variability. They conclude the final chapter of this book with the comment that random variations in language ultimately originate from the fact that human ways of expressing meaning are far from unique.

2 A Transdisciplinary Perspective on Chance

One of the insights of this collection of articles that struck us as meaningful when looking at chance from such diverse disciplinary perspectives is that two aspects return in many of the contributions, namely the contextuality of chance and its role in explanations.

Contextuality of chance is most clearly seen in scale-dependence, which is found in many biological ecosystems (cf. De Kroon and Jongejans). What seem to be random events at a lower level can produce stability at a higher level. For example, seeds are dispersed at random by the wind, then may germinate into a plant or disappear. Another example is the origins of language variation. Ideas about random origins will be different if studied at the level of species, language in general, different languages, or individual speakers of a given language (Van Hout and Muysken). Random genetic mutations (Brunner) provide yet another case in point. They originate at a molecular level but, subsequently, have causal or probabilistic consequences for genes, individuals, species, ecosystems and thus, ultimately, for the planet as a whole. In history, what seem to be a small-scale state of affairs (such as the legendary beauty of Cleopatra's nose) can have huge consequences for nations and even epochs (Hekster). As a final example, in economics, the (random) individual psychology of a single investor interacts with the rather more deterministic psychology of the 'masses', for example, during the tulip mania in 1637 or the dotcom bubble in the 1990s (Weitzel and Rosenkranz).

Another instance of the contextuality of chance is its perspectival nature. In mathematics (Terwijn), no *absolute* notion of randomness can exist, and in order to

properly define the notion, one has to specify *with respect to what* the supposed random objects should be random. Thus a random object is random with respect to a given type of definition, or class of sets. Strikingly, this view is comparable to the theological view presented in literary form in the biblical book of Job (Van Wolde). In the narrated divine speech out of the whirlwind, chance is related to a multifocal view of a universe and interpreted in terms of perspective: God, reflecting on the universe and its inhabitants, states that he does not share the perspective of the stars, weather phenomena, or animals, and that he does not even share the moral convictions of human beings who only want him to share *their* perspective, such as their ideas of justice. Thus what seems to be coincidental at the level of humans (or animals and plants) may be the effect of order at a higher level.

Secondly, throughout history including contemporary science, chance has been used both as an explanation and as the hallmark of an absence of explanation. Thus one may wonder if these apparent antipodes are really as antithetical as they seem. Historiography itself is a prime example. One could argue that Western philosophy would have emerged without Plato, or that there would have been a Scientific Revolution without Newton. But would there have been a communist Russian Revolution without Lenin, or a Holocaust without Hitler? If not, the actual occurrence of these momentous events in history was eventually *caused* by the *random* events of the births of these particular individuals. Similarly, parents with a severely handicapped or stillborn child may feel that their misfortune has no explanation, while their doctor may say it was *caused* by a *random* genetic defect. Appeals to God as the instigator of certain random events play a similar role. In quantum physics it could be claimed that radio-active atoms decay *because* of random events, or it could be said that this decay cannot be explained. The Fine-Tuning Argument brings this dual role of chance to a head, as many contemporary secular scientists seem perfectly happy to attribute the occurrence of life to chance, whereas others regard this as the lack of an 'explanation', and look elsewhere.

The reader is invited to also look at other chapters from these two angles, or indeed from any angle he or she prefers, as chance is an infinitely rich phenomenon that will continue to fascinate humans as long they live. We hope this book will challenge our readers as much as it did the authors.

Conceptual and Historical Reflections on Chance (and Related Concepts)

Christoph H. Lüthy and Carla Rita Palmerino

Abstract In everyday language, the use of such words as "chance," "coincidence," "luck," "fortune" or "randomness" strongly overlap. In fact, in some languages, such as German, they coincide in one word (*Zufall*). In others, there is a clear separation between chance events with positive connotations (e.g., "luck," "fortune") and those with bad ones (e.g., "accident," "hazard"). In this essay, we try to sketch the main lines of development of several of these concepts from the ancient Greeks up to modern times, or more precisely, from Democritus and Aristotle up to the world of quantum mechanics. Three elements emerge with particular force. First, "chance," "fortune," "randomness," etc. are in some instances invoked as explanations of events, but in others designate events that occur without an explanations. Second, the meaning of these terms only becomes clear when one understands which alternatives they exclude. Finally, it is conspicuous to see how, after a rigid exclusion of "chance" or "randomness" from the domain of scientific explanation in the early modern period, they were restored to full glory in nineteenth- and twentieth-century biology and physics.

There exists a cluster of words with which we designate events that in some way or another surprise us, either because we didn't expect them, or because they are out of the ordinary, or because they seem inexplicable. "Chance," "coincidence," "randomness," and "luck" are words that belong to this category of surprise. Sure enough, each of them has more technical meanings, particularly when used in

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specific scientific and non-scientific contexts; take, for example, a mathematically precise notion such as Martin-Löf randomness.[1] But as far as everyday language is concerned, our terms strongly overlap. Phrases such as "I met him by chance," "this was an extraordinary coincidence," "I was randomly chosen," or "I was lucky enough to escape" all gesture at the fact that we couldn't have predicted what in fact happened to us or to someone else.

All of these terms are popular, and some are used with great frequency. And yet, it is very difficult to say what exactly they mean. It is impossible to develop either a coherent theory or a single narrative around them. They are simply too soft conceptually, too imprecise, and in fact even contradictory. Most people would probably agree with the Enlightenment philosopher David Hume that "chance, when strictly examined, is a mere negative word, and means not any real power which has anywhere a being in nature." (Hume 1748, Ch. 8.1).

One important reason why it is impossible to give a coherent account of this negative word and of its siblings is that they are used both to offer an explanation and to signal the lack of an explanation! Two examples will suffice to demonstrate this. In the sentence, "She didn't know the game, and that she won was sheer luck," the word "luck" signals the absence of a good explanation (such as routine or skill) to account for the fact that someone won at a game. The logic is quite different in the sentence, "through this lucky coincidence, she managed to win the elections." Here, the "lucky coincidence" offers an abbreviated explanation. The "coincidence" might refer to the fact that Harry, the obvious candidate, had suffered a stroke, and Lucy, his opponent, had on the same day been imprisoned, so that Theodora, whose ambitions had previously seemed implausible, could now win the elections. While in the first sentence the expression "sheer luck" signals the absence of a convincing causal explanation, in the second the expression "lucky coincidence" provides the explanation, while obviously also indicating its unforeseen nature.

Depending on the context, "chance," "coincidence," "randomness," or "luck" do not only indicate the presence or absence of a recognizable causal logic, but they also indicate unknown probabilities, which might or might not be calculable. "Chances are that you won't make it," or "If you are lucky, you might still catch that train," are phrases which imply an embryonic form of probabilistic reasoning of the type "what are the odds that x happens?"

Explanation, lack thereof, or intuited probabilities: it is in this ill-defined, swampy area that the terms we are examining here are located. As a consequence, Madam Fortune, the mythological personification that rules over these swamps, will necessarily also assume multiple roles. At one extreme, she will manifest herself as a divine figure that determines our fate; reference to her will in that case provide a coherent answer for explaining why things that for us had been unpredictable had nevertheless happened. At the other extreme, she is as helplessly exposed to

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[1]On different mathematical definitions of randomness, see Sebastiaan Terwijn's chapter in this book.

circumstances as we are. A fickle woman placed on the allegorizing weather vane who is swept about by the winds, she is herself the object of unpredictable influences. Explaining an event through fortune characterized in the latter way amounts to empty prattle, as it merely moves unpredictability to a different level.

Despite the elusive and contradictory explanatory value of this cluster of words, there are interesting things than can be said about them. In our first section, we will first try an etymological approach. There, we will encounter a strong presence of falling dice as well as of lots, straws and other literally "aleatoric" objects of gaming and decision making, including the emblematic Wheel of Fortune. But we will also witness a strong and unresolved tension between viewing fortune and chance as a final (possibly divine) explanation for unexpected occurrences, and that of depicting them as merely a higher level of unpredictable randomness.

Our main approach is, however, historical. We will in some detail survey a number of key moments in the history of scientific (or natural philosophical) thought, from the divine fate of Greek tragedy and the chance swerve of Epicurean atoms through the deterministic machine world à la Descartes up to the reintroduction of chance and randomness in scientific theories as diverse as evolutionary theory and quantum physics. In this section, we will see that, as a general rule, philosophy and science have repeatedly tried to drive chance and coincidence out of their domain—unless they could stand for a precise type of causal factor that was required for a specific type of physical explanation—but that, time and again, chance entered anew through the back door.

We will end by concluding that our terms are best understood *ex negativo*. In order to understand what scientists or philosophers of past and present ages mean when they attribute something to chance, coincidence, randomness or luck, it is indispensable to understand what it is that they wish to exclude. Is it necessity, fate, determinism, causal knowledge, regularity, high probability, or something else? Given the obvious vagueness and contradictoriness of the connotations of our original set of words, it will come as no surprise to see that their contraries are just as ill-defined. Still, there is a strong heuristic advantage to this exercise. Being aware of what it is that we wish to exclude, we, the readers of this essay, will at least have some greater clarity of what it is that we implicitly wish to affirm with our underdetermined words.

1 Etymological Prelude

1.1 Dice and Other Falling Objects

We have opened this essay with the observation that "chance," "coincidence," "randomness," and "luck" may possess precise meanings in specific scientific and

cultural circumstances, but that in everyday language, their meanings overlap.[2] Let us now add that this overlap is much greater in one language than in another. A particularly striking case is German (and the same is true for Dutch), where the word "Zufall" covers all four English terms: "*eine zufällige Begegnung*" is "a chance encounter"; "*ein seltsamer Zufall*" is translated as "a rare coincidence"; "*ein zufälliger Passant*" would be "a random passer-by"; and "*ein Zufallstreffer*" could be translated as "piece of good luck." Now, *Zufall*, this all-encompassing German word, is an old but literal translation of the Latin *accidens*: "something that falls down" or "upon."

   Cadere, the Latin verb for "to fall," stands in fact at the root of several of the words that we are investigating in these pages. To begin with, there is of course the Latin noun *casus*, "the fall," a word that can describe the falling of snow, but also everything else that literally "befalls" us, however improbable it may be. *Casus* is therefore also the Latin word for "chance," "coincidence," or "luck." In Italian, it has retained precisely that meaning: "*Sei per caso in città domani?*" is literally "Are you by chance in town tomorrow?" The English word "case," which barely hides its Latin origin, has lost most of the original significance of *casus*, although the adjective "casual" still retains some of it, as when we speak of a "casual meeting."

   What "befalls" us can be pleasant or unpleasant. Whereas *Zufall* is neutral in that respect (an event can be a *glücklicher* or *unglücklicher Zufall*), the Latin *accidens,* of which *Zufall* is a translation, has in many languages assumed a predominantly negative connotation. While the adverb "accidentally" still means "by chance," the noun "accident" has clearly negative connotations. The phrase, "It was an accident," would nowadays never be used with reference to a "fortune" won at the lottery, but most certainly so as to explain why the window is broken. The same negative connotation of "accident" is found in French or Italian, while in German, the oddly inauspicious prefix *un-* in *Unfall* does the same trick. Significantly, the French word *hazard*, which ultimately seems to go back to an Arabic expression relating to the throwing of dice, has had the same double fate as "accident": while *par hazard* is emotionally neutral, simply meaning "by chance," the English "hazard" and "hazardous"—as in "hazardous waste"—are negatively charged.

   But the element of "falling" is even more pervasive than that. Just like "case," the English word "chance" also derives in the last instance from the Latin verb *cadere*. It has however made a certain detour, deriving ultimately from *cadentia*, "the ways in which the dice fall," which later became *chéance* in old French. Just like "hazard," which—as mentioned before—may derive from an Arabic word that also refers to the unpredictable way in which the dice fall, "chance" eventually came to designate whatever happens without us being able to determine it. Seen in

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[2]The following etymological paragraphs were written on the basis of the *Oxford English Dictionary*, 2nd ed. (1989), s.v.; *Historisches Wörterbuch der Philosophie*, voice "Zufall"; *Duden. Deutsches Universalwörterbuch* (2007), s.v.; the *Online Etymological Dictionary*, s.v.; as well as various Latin, Greek, French, German and Italian dictionaries.

this light, Julius Caesar's famous pronouncement, "The die is cast" (*alea iacta est*), which announced his much thought-over decision to cross the Rubicon and start a civil war, would be an oddly inappropriate metaphor, given that Caesar's was everything but a random decision. But in fact, it appears that he spoke the phrase in Greek, citing a line from a comedy by Menander; the Greek phrase *anerrhiphtho kubos* should in fact be translated as *alea iacta esto*, "let the die be thrown," referring not to the decision taken, but instead to the uncertain outcome of the enterprise that was to follow from it (Lewis and Short 1879, s.v. *alea*).

The word "coincidence" derives from the Latin verb *cadere* in a more visible way. A "coincidence" takes place when things "fall" (*cadere*) "together" (*co[n]*-) and "upon" (-*in*) something. The word is not ancient Latin, but medieval, and it seems to have first been used in astrology, where *coincidentia* referred to the joint influence of multiple planets. This genealogy gives us an indication of a basic difference between "chance" and "coincidence": the latter requires more than one thing to happen at the same time. In the sentence, "By chance, I was born into a rich family," you could not replace the first word by "by coincidence." Meeting your neighbour in a far-away vacation location, by contrast, certainly qualifies as a coincidence; after all, you both had to travel there in order for your paths to cross.

These various shades of "falling" are instructive. It is certainly noteworthy how many terms there are in English and other languages that express surprise at a certain event or "occasion" (yet another such word) in terms of a "fall." It is as if the *casus*, "chance" or *Zufall* always fell down from above, literally "out of the blue." The proverbial "stroke of luck" would therefore have to be represented by the gesture of a fast downward arm movement.

More indirectly, the same is true for other words, such as "luck," which—though related to Germanic words for happiness and fortune—seems to have entered English as a gambling term. Like "accident," it might originally have referred to the way in which the dice fall, although this time with a uniquely positive connotation. The "falling" of the *casus* has here been confined to the descent of circumscribed objects on the gambling table. Still, the downward direction has remained intact.

1.2 Fortuna, Wheels and the Lottery

Still related to gambling, but involving quite a different type of movement, is the Wheel of Fortune. In late Antiquity and medieval times, this wheel was the constant attribute of the goddess Fortuna, who was spinning it (either blindfolded, or else maliciously watching) as men and women were literally "rising to fortune" or descending rapidly, "losing their fortune." Whether blind or seeing, Madam Fortune was a puppeteer, we mortals were her puppets. But then, as we have mentioned earlier, she was also regularly depicted in a passive role, herself the victim of unpredictable change. A particularly striking depiction of this latter figure was given by the Roman tragedian Pacuvius, who sketched the following portrait:

"Philosophers proffer the view that Fortune is insane and blind and stupid, /And they teach that she stands on a round, spherical rock: /They assert that, where chance (*fors*) pushes that rock, there Fortuna will fall."[3] Once one realizes that the word *fors*, "chance," stands at the root of the name of the goddess Fortuna, one begins to stare down the mirror cabinet of an infinite regress: we get a situation in which we humans rise and fall, tied to the Wheel of Fortune, while the goddess herself falls from the ball on which she stands, pushed in turn by "chance" (of which one had mistakenly expected her to be the ruler and embodiment).

In his demolition of the pantheon of pagan deities, Saint Augustine in *The City of God* directs his glance also at Fortuna (Book IV, Ch. 18). Why, he asks, is Fortuna traditionally associated with "felicity"—the Romans had initially endowed her with a cornucopia, and had thus viewed her as an exclusively positive figure—although we know that one can also have "bad fortune?" Such an identification doesn't make any sense, according to Augustine. Further, why should Fortuna be considered a goddess, if she can also bring about bad things? Plato tells us clearly that it is the essence of gods to be good; "how, then, is the goddess Fortuna sometimes good and sometimes bad? Is it perhaps that when she is bad, she is not a goddess, but is suddenly transformed into a malignant demon?" (Augustine 1998, 164). And finally, what should we make of the fact that the name of the goddess is also derived from the word *fortuito*, that is, "by accident?" How can she be a goddess if what we ascribe to her happened accidentally? In a few lines, Augustine exposes all the contradictions that reside in the concept of a deified principle of randomness, and all the inner tensions between a principle that should account at the same time for luck, happiness, destiny, the vicissitudes of life and personal success.

It is surprising to see that despite Saint Augustine's debunking, Fortuna was highly popular in the Middle Ages. In the meantime, however, her cornucopia had definitely disappeared for the wheel (Vogt 2011). Fortuna had changed from the positive figure ridiculed by Augustine into a highly ambivalent one. This may come as a surprise, as the idea of the random rise and fall of people (and peoples) is of course profoundly un-Christian, as it contradicts the notion of providence. And yet, it survived, and in fact thrived, in the hands of medieval Christianity. Dante Alighieri eulogizes Fortuna as nothing less than the first creature of God, who rules over the world and makes it spin about according to her occult whims, which are ominously invisible "like the serpent in the grass." With respect to God and to humans, she is "general servant and leader," respectively (*Divina Commedia*, "Inferno," VII.78–84).

It has been argued that the popularity of Fortuna in the Middle Ages is due to the late Roman author Boethius, in whose *Consolation of Philosophy* Fortuna makes a striking appearance, declaring:

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[3] Pacuvius, ed. O. Ribbeck (1897), vol. 1, vv. 365–375: "Fortunam insanam esse et caecam et brutam perhibent philosophi,/ Saxoque instare in globoso praedicant volubili:/ Id quo saxum inpulerit fors,/ eo cadere Fortunam autumant."

> This is my art, this the game I never cease to play. I turn the wheel that spins. I delight to see the high come down and the low ascend. Mount up, if you wish, but only on condition that you will not think it a hardship to come down when the rules of my game [*ratio ludicri mei*] require it (Boethius 1897, II.2p, trans. modified).

Curiously, while Fortuna goes about her pagan business of causing the rise and fall of people, she seems (at least in this passage), to give us the choice between participating in the "ludicrous game" or abstaining from it. In fact, she quickly recalls to her listener the brutal fall of the Lydian king Croesus. The theme of the fall of kings—and here we are back with the previous etymology, of the *casus* and the "accident"—was popular throughout the Middle Ages. The *Carmina Burana* warns the powerful of the inevitable turning of the wheel: "too high up/ sits the king at the peak/ let him beware of ruin!"[4] In fact, a particularly popular image was that of four kings attached to a wheel, with one ascending (*regnabo*, "I will rule"), one on top (*regno*, "I rule"), one dethroned and descending (*regnavi*, "I have ruled"), and one at the bottom (*sum sine regno*, "I have no kingdom").

However, Boethius' Fortuna does not only seem to give us the choice between taking a ride on her wheel or leaving it, but Boethius himself, in Stoic fashion, recommends that we should seek our tranquillity irrespective of the vicissitudes afflicting our personal lives. Moreover, he suggests that there is a higher, maybe Platonic or else providentially Christian level at which it all makes sense. It has in fact been suggested that the ubiquitous medieval representations of Fortuna should be interpreted through the influence of Boethius (Vollmer 2009). The advantage of this explanation is that it helps us explain how it was possible that the pagan Wheel of Fortune could end up defining the shape and iconographical program of cathedral roses and church interiors (see Fig. 1).

An entirely demythologized, contemporary version of the Wheel of Fortune is the lottery wheel, which is inscribed by numbers corresponding to lottery tickets and a pointer pointing to the rim. The wheel is spun, and when it comes to a standstill, the ticket carrying the number corresponding to the number indicated by the pointer wins. With this device, we have arrived at our last set of terms. Originally, the "lot" was any object—a piece of straw, a chip of wood with a name on it, or, as in so many earlier examples, a die—that was used to determine someone's share, for example in an inheritance. A "lot" of land (and even the trivial "parking lot") still refer to that process of "random allotment" as does the phrase, "what falls to a person by lot." But when we recall the figure of Fortuna spinning her wheel, or deciding the outcome of the draw or the casting of dice, we will understand how "lot" and "lottery" could also come to refer to any "(ill-)fortune" that life has in store for us. The village lottery may assign a lot of land to us; the phrase "It was my lot to be born poor" refers instead to a lottery in which I was not able to buy even my own ticket.

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[4]*Carmina burana* (1974), song 16: "nimis exaltatus / rex sedet in vertice - / caveat ruinam!".

Fig. 1 Fortuna (1372) depicted on the floor of the Cathedral of Siena. Is the ruler on his throne (*regno*) about to fall (*regnavi*), or is he rather, solidly enthroned, supervising the ascent and descent of the other figures? Strikingly enough, the four philosophers in the corners are all pagan: Euripides ("I have told you, son, to seek fortune through labours," from *Elektra*); Seneca ("A great fortune is a great slavery," from *De consolatione*); Aristotle ("Great fortune makes men more petulant," from the *Politics*); and Epictetus ("Glory not in the gifts of fortune, but in the goods of the souls," from the *Enchiridion*). Their advise has no providential, Christian, or eschatological overtones, but combines classical prudentialism with the topos of *virtus vincit fortunam* ("virtue/determination wins over fortune"): don't seek fortune, but if you do, seek it through hard labour; but be beware that it will negatively affect your character; and anyway, "it's what's inside that counts."

1.3   Randomness and Reckoning with Fortune

With the "randomness" of the lottery's decision-making process, we have arrived at the last word in our etymological survey. There was once an Old Frankish word, **rant*, cognate to the English "running," which eventually became *randir*, "to run fast," in Old French, as well as *randon*, meaning "rush" and "disorder." From the French, it migrated to English, where it became "at random," which originally meant, "at great speed" and hence "without order" and "haphazardly." By 1650, it had acquired one of its current meanings, by referring to events that took place "without definite aim or purpose." Originally, it was actor-bound: an individual was said to act "randomly," that is, without purpose, for example by pointing at

someone while blindfolded. The use of the word as an adjective, as well as the identification of "chance events" with "random events," seem to be of more recent date. Of even more recent date are the mathematical theories of randomness, which are an extension of classical probability theory, or the quantum-mechanical randomizers.

These recent developments are interesting from a philosophical perspective. For once one equates randomness with chance, and once chance becomes calculable, as it did over the past three and a half centuries thanks to the mathematical determination of probability, one somehow also domesticates chance, randomness, and possibly even one's lot. Looking at a set of global statistics, one may now state: "The odds were high that I would be born poor." In Boethius' *Consolation* (II.3p), we have Fortune asking defiantly: "Do you wish to count out the score with Fortune?" (*Visne igitur cum fortuna calculum ponere*?). Through the mathematization of probability, we are attempting to do just that: "Reckon with fortune." As several chapters in this book document, this reckoning has taken on high forms of abstraction in various disciplines.

And yet, despite all domestication of chance, luck, fortune, coincidence and randomness in the specialized disciplines, the old meanings have not disappeared. Fortuna may no longer be a deity, but the surprise, the rage, the joy, and the bewilderment that something particular happened to us, of all people, that it had to happen just then and there, has not vanished. Nor have most of the terms and expressions that the Greeks, the Romans and our medieval ancestors used.

Did, then, our etymological exercise tell us anything useful? If we had hoped for a conceptual convergence between the words investigated here, then we were (predictably) deluded. Between the goddess who spins the wheel, the blind and hasty rush forward, life's lottery, the ubiquitous falling of dice, and all other unpredictable coincidences and accidents, there is little that amounts to any over-arching notion of how we must "account" for the unforeseen events in life, nature or history. The divergent uses of the words we investigated, and even of single words, is however illuminating. To remind ourselves of the most dramatically ambivalent word, "fortune," we have seen that Fortuna could appear as a goddess of "good fortune," with her cornucopia at the ready; she could be a (still personified) semi-independent cosmic force governing over chance, coincidence and randomness; she could be a way of life that one could choose to follow or else ignore; but "fortune" could also be the well-deserved result of hard work, the danger being, however, that it might corrupt our character.

To be aware of the internal tensions between the various sub-meanings of the words seems to us an important step towards a comprehension of what these words can possibly be intended to achieve. But their full complexity only becomes apparent once one places them into the philosophical and scientific context in which their role in the causal nexus of things was examined. This is what needs to be done next.

2 History

2.1 Greek Origins

Let us therefore turn to an examination of a number of key moments in the intellectual—that is: philosophical and scientific—evolution that our words have undergone, and the explanatory (or causal) role that was attributed or denied to them. We must start with ancient Greece, because it is there that our current terminology takes its origin. It is also there that we find, for the first time in Western intellectual history, a debate about the status of unexpected events and the way we must deal with them conceptually.

We have begun our essay with the element of surprise that characterizes the various terms in question. In ancient Greece, the word that designated an unexpected turn of events in a human life or in the observed natural world was *tuchê*. In comedies, tragedies and in works of historiography, *tuchê* is invoked to designate such unforeseen events, which may derive from the gods or from mere fortune [*tas tôn theôn tuchaskai to chreôn* (Euripides, *Hercules Furens* 309–11)]. If from the gods, *tuchê* is of course providential, which means that what to us may seem "by chance," is instead "by necessity" or "will" at a higher, divine, level. The existence of such a two-tiered logic explains why Sophocles can speak, in what at first looks like an oxymoron, of "necessary chance" (*anankaia tuchê*, *Ajax* 485, 803), a combination of words that in other texts is rendered as "fate" (*moira*, *potmos*). But while the older tragedians Aeschylus and Sophocles seem to have equated *tuchê* with fate, their younger colleague Euripides was less inclined to attribute all unforeseen events to a providential plan (Dudley 2012, 137). In *Hecuba* 488–491, a certain Talthybius wonders, for example, whether it is the gods or rather chance (*tuchê*) that rule over human affairs, thereby clearly separating the two (Lawrence 2013).

2.2 Aristotle

Distinctions and reflections that in literary works were merely adumbrated were made most fully explicit in that potent thinker whom Dante called "the master of those who know," namely Aristotle, whose philosophical and scientific teachings were to define Western university education until the end of the seventeenth century. In various of his works, we find Aristotle reflecting on the possible role that chance might play in the natural world and in human affairs. Always an acute analyst of terminology, he carefully examined various types of chance, distinguishing between *tuchê*, on the one hand, and such related concepts as *to automaton* (a type of spontaneity), and *eutuchia* (which might be translated as "good fortune").

Aristotle's most extensive treatment of chance is found in book 2 of his *Physics*. As is often the case, Aristotle starts his analysis with an historical excursus.

Previous philosophers have failed to give an account of chance, he tells us, which is all the more surprising as some of them have attributed to chance a fundamental role in their physical systems (*Physics* 195b30–196b9). Aristotle here thinks of Empedocles' cosmogony, which relies on air that moves upwards by chance and speaks of the haphazard origin of limbs of animals; but he thinks even more clearly of Democritus, who maintains that "the cosmic order came by chance […], whereas neither animals nor plants are, or come to be, by chance, but are all caused by Nature or Mind or what else." Aristotle laughs this idea out of court, arguing thus:

> But if this really were so, that very fact ought to give us pause and convince us that the matter needs investigation. For, in addition to the inherently paradoxical nature of such an assertion, we may note that it is exactly in the movements of the heavenly bodies that we never observe what we call casual or accidental variations, whereas in all that these people tell us is exempt from chance such things are common. Of course it ought to be just the other way (Aristotle 1957, 196a25–196b5).

Famously, Aristotle inverts the order: for him, "regular and customary successions," such as those observed in the heavenly motions, must happen by necessity (*ex anankês)*, whereas the terrestrial realm is defined by a great degree of randomness. Regular necessity is observed throughout the superlunary sphere, where the sun, the planets and the stars are located and which is defined by one single element, ether, and by constant, circular movements. By contrast, in the sublunary sphere, where the four elements constantly mix and unmix, objects continuously come about and perish again. Here, where we find irregularity and surprising events, we may truly speak of products of chance (*hê tuchê kai to automaton)*. Let us here remember that this stark Aristotelian opposition between two cosmological domains, each with its distinct ontological status and its own set of physical laws, was to break down only in the aftermath of Copernicus and Kepler in the course of the seventeenth century.

Aristotle admits that, in our sublunary domain of permanent change, "what we call luck or chance corresponds to some reality" (Aristotle 1957, 196b15–17). At the same time, he rejects the suggestion that *tuchê* should be viewed as a specific type of causality. Instead, chance events should be regarded as accidental, that is to say, concomitant effects of a definite cause: "*Tuchê,*" Aristotle writes in his *Physics*, "is a cause only accidentally (*kata symbebêkos)*" (*ibid.*, 197a14f). But what does it mean to be an accidental cause? In his *Metaphysics*, Aristotle defines "accident" as that which happens "neither necessarily, nor usually," adding that there is "no definite cause for an accident, but only a chance, i.e., indefinite cause (*aoriston)*" (Aristotle 1933, 1025a15). If a man goes to the market and "accidentally" meets his debtor, "the reason of his meeting him was that the wanted to go marketing; and so too in all other cases when we allege chance as the cause, there is always some other cause to be found" (Aristotle 1957, 196a1–8). Here, then, we have the typical surprise moment mentioned in our introduction. The man may have wanted to buy cheese and vegetables, but, "as it happened," he encountered his debtor. That the verb *sumbainô*, of which *symbebêkos* ("accident") is the past participle, literally means "to walk together," is most suitable for this specific Aristotelian example, as

it provides a quite visual model for what we have earlier defined as a "coincidence": two men walking, each steered by his own intentions, to the market, but "accidentally" ending up in each other's company.

In order to make sense of Aristotle's distinctions, one has to remember that his entire universe, and the causality that is active in it, is everywhere purposeful and goal-driven, so that the explanations he offers tend to be teleological. In such a universe, *tuchê* is an "accident" in the sense that it designates those events that eschew all purposes. In the natural world, a typical class of "accidents" is constituted by monstrous births, which also include female babies and which may be regarded as "failures of purpose in Nature" (Aristotle 1957, 199b4), in the sense that accidental factors hindered the natural development of the seed.[5]

Being "characteristic of the perishable things of the earth" (Aristotle 1937, 641b15), chance manifests itself above all in the domains of biology and of human action. Sometimes, Aristotle in fact wishes to limit the scope of *tuchê* even further, restricting it to rational behaviour. "Neither inanimate things nor brute beasts nor infants can ever accomplish anything by *tuchê,* since they exercise no deliberate choice." By contrast, the larger category, *automaton*, describes cases in which "*any* causal agency incidentally produces a significant result outside its aim" (Aristotle 1957, 197b19–23). Spontaneous generation, in which the presence of warmth can bring about worms or insects in a heap of dung or a warm puddle, is a case in which non-rational agents bring about a meaningful product by a sheer concurrence of circumstances.

If taken in this restrictive meaning, *tuchê* becomes the object of ethical reflection. In his *Eudemian Ethics*, when discussing the cause and the ethical bearing of good luck (*eutuchia*), Aristotle formulates an interesting paradox: we tend to call those persons "fortunate" (*eutuchês*) who "without the aid of reason are usually successful" (Aristotle 1935, 1247b27–28). This is however in contradiction with the accepted definition of chance or fortune (*tuchê*), which implies that something happens neither always nor even regularly (*ibid*., 1247a31–35). In order to resolve this paradox, Aristotle distinguishes between two types of fortune. The first is due to the aid of a god, whereas the second type of fortune is that of persons who are successful because they instinctively choose for the right course of action. Both sorts of good fortune are "irrational," in the sense that they are not obtained through our conscious choice, but the first is continuous, whereas the second is incidental (*ibid*., 1248b5–10).

What Aristotle's sundry ethical, physical and biological reflections on chance have in common is an emphasis on the inherent lack of reflection, premeditation or, in short, rationality. Good luck (*eutuchia*), chance (*tuchê*) and spontaneity (*automaton*) are all *paralogos*, unaccountable by reason, either because there is no purpose

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[5]Both in *Physics* and in the *Generation of Animals*, monsters are regarded as "chance substances"; see Dudley 2012, 171, 175.

involved (as in the case of worms being spontaneously generated in a heap of dung), or because the result of an action was not intended (as the man meeting his debtor on the market square) (*Physics*, 197a10, 18–20 and *Eudemian Ethics*, 127a33–38). It is precisely their undirected, irregular and contingent nature that also renders chance events "unscientific." For Aristotle, "science" (*episteme*) designates a psychological state in which the mind possesses knowledge with regard to the causes of an event. In the case of accidental events, the cause is however "unrecognizable," "indefinite" and "irrational" (*paralogos*) (*Physics*, 197a8–35).

2.3   The Ancient Atomists

So much for Aristotle himself. Let us however return to the atomists he criticized for what he took to be a misguided cosmogony and a misleading causal theory. We recall from above that Aristotle ridiculed Democritus specifically for suggesting that the cosmic order was the product of chance. Interestingly, the doxographer Diogenes Laertius provides a different version of Democritus' convictions, ascribing to him the view that "everything happens according to necessity; for the cause of the coming-into-being of all things is the whirl [that is, the atomic vortex which gave origin to the world], which he calls necessity" (Laertius 1925, IX, 45). Similarly, the only extant fragment of Leucippus, who may have been the inventor of the concept of atom, reads: "Nothing exists at random (*matên),* but everything for a reason (*logos)* and by necessity (*anankê*)" (Kirk et al. 1983, 420).

Why should Aristotle then have attributed to Democritus the view that the world came about by chance (*apo tautomatou*)? According to Edmunds' influential interpretation, he did so to stress the purposeless character of the atomistic cosmos (Edmunds 1972).[6] We recall from above that according to Aristotle's own definition, *automaton* "means an occurrence that is in itself to no purpose" (*Physics* 197b25–30). In other words, what to Leucippus and Democritus was "necessary" and hence the contrary of "chance" would for Aristotle have been its very opposite, namely a blind and therefore unguided and random event. Put differently, what was a deterministic "necessity" to one philosopher was mere "chance" to the other. This is a typical example for the phenomenon that will be discussed in our conclusion: the terms with which we are engaging in this chapter can only be understood if one knows the alternative terms they wish to rule out.

Indeed, as A. A. Long has perceptively pointed out, chance (*tuchê*) is incompatible with necessity (*anankê*) only if the former is taken to indicate events that are the result of sheer contingency and indeterminacy (Long 1977, 67–68). This observation takes us to Epicurus, the first philosopher to have explicitly introduced

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[6]A similar point is made by Cherniss (1935), 248–49, and Long (1977), 67.