KOSTAS KAMPOURAKIS

TURNING POINTS

How Critical Events Have Driven Human

EVOLUTION, LIFE, and DEVELOPMENT

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PREFACE

My own life, like everyone else's, has been full of critical events that have driven it in the direction it has taken. As a child, I was prone to believe that there is purpose in one's life. A main reason for this belief was that my father, a Greek army officer who happened to serve in the Cypriot armed forces, was severely injured—and almost died—during the Turkish invasion to Cyprus in July 1974, while my mother was pregnant with me. He survived because he was lucky enough to be found by a comrade and be transported to the hospital, where he was, again, lucky enough to avoid a leg amputation by mistake—events totally contingent. He is now seventy-two years old and in full health, and he still believes that there was a purpose in all that. I am his lucky child, he often says, as he believes that he did not die there for a purpose: in order for me not to grow up as an orphan. His beliefs and my own life were certainly contingent upon the events of July 1974. My life would have been totally different had he died there. To say the least, my young brother would not have been born. For these reasons, I initially accepted that there must have been a purpose for his survival: that I would not grow up as an orphan and that my brother would be born. This was what my father believed; but I must note that he never tried to impose any kind of fatalistic thinking on my brother and me. It was just what he believed.

But as soon as I started my undergraduate studies in biology, my beliefs and worldviews changed—radically. I soon developed a different understanding of life, one dominated by contingencies and conjunctures, and I stopped believing in a plan and purpose in life. That was an important shift. Being a city boy, I had only a limited interaction with domestic animals, when we visited my father's parents in their village in Crete during summer. Like many others, I also grew up watching all of those

anthropomorphic, happy-animal, happy-ending children's films. But as an undergraduate student, I started a more sophisticated exploration of nature, not as an amateur naturalist but through books and documentary films about nature. The extreme violence that existed in nature made me reconsider my views about the principles that govern life, with death being a major one. An event of this kind also dominated my childhood. Two years after I was born, my father's brother died from a heart attack at the age of twenty-nine. Everyone was talking about him and about how unlucky he was. As a child, I always found it hard to understand why he died; why I never had the chance to get to know that person who was admired by everyone who knew him and who had just gotten married a few weeks before his sudden death. I wanted to hope that there was some good reason for this, but, eventually, I realized that there was not; he just died (needless to say, I doubt that my father ever saw any purpose in that devastating event like he saw in his surviving his injuries). Any remaining thoughts I had about plan and purpose in nature had vanished.

My whole professional life, and my writing hobbies as well, have to do with understanding, teaching, and learning biology. One could have thought that I was meant to do that, because I do practically nothing else, except for spending time with my family and friends. Reading and writing about biology is a defining feature of who I am. However, how I ended up studying biology is a funny example of the impact of contingencies on one's life. I finished school before I was eighteen years old, and participated in the Greek national exams in 1992. At that time, university candidates were supposed to be examined on four subjects, and could participate in the exams up to three consecutive times. An important detail: one could submit for some of these subjects the high grades one had gotten in past exams, and then, therefore, be examined only in the remaining subjects. This means that those who were finishing school and were participating in the exams for the first time, being examined in four subjects, had to compete with other candidates who were participating for the second or the third time and were being examined in, for example,

only two subjects after having spent a whole year working on them. To show the impact of these conditions one need only look at my peers: out of the ninety first-year undergraduate students of my cohort, I can think of only myself and two or three others who had just finished school at the time. All of the other students were one or two years older than us.

In line with the trend of the time for any reasonably good student interested in the life sciences, my "fate" was to become a medical doctor; this was also the hope and wish of my whole family. I was always interested in biology, but at the time there was not much going on in Greece that was widely known, and so I decided to try to enroll in the study of medicine and see after that what I would do. However, there were already employment issues because the field was inundated with medical doctors (as a result of the I-want-to-become-a-doctor trend); so, following my father's advice, I decided to become a medical doctor in the Greek army. Students in Greece apply not directly to universities but to the Ministry of Education, submitting a file with their preferred university departments—at that time this was done *before* the exams. Therefore, I put the military school for becoming a medical doctor first, the department of biology in Athens second, the department of biology in Thessaloniki third, and the remaining biology departments after that. I also added a few technical schools just to have them. I should note that these departments did not ask for a minimum score for accepting students. Rather, they accepted a certain number of students, for instance, the ninety applicants with the best scores among all of those who had mentioned that department in their application—whatever that score was.

I actually wanted to study biology, but my family and family friends had convinced me that professionally I would be a failure. It so happened that I ended up having a score of 5695 points out of 6400. The last student to enter the military school for medical doctors had 5720 points, so I was out; the last student to enter the biology department in Athens had 5694, one point less than me, even though there were two others between us; and the last student to enter the biology department in Thessaloniki had

a slightly lower score. Therefore, I ended up in the department of biology in Athens, where I was living, and after a year as an undergraduate (and a second, failed attempt, because of my limited willingness and motivation, to enter the medical school for army doctors), I decided that I would stay in biology. If I had ended up in the biology department in Thessaloniki, it's unlikely that I would have gone there, because it was not possible at the time for me to study in another city; therefore, I would have probably studied carefully to participate in the national exams the next year. Since I wouldn't have enrolled in university studies, I would have probably been highly willing and motivated and thus would have a higher probability to enter the medical school. Luckily, for medicine and for me, this never happened.

My story shows the combined impact of different kinds of factors in human life. On one hand was the surrounding environment (i.e., how exams for entering the university worked), which would be the equivalent for natural conditions for development and evolution. On the other hand, there were my personal decisions, for instance, to decide to start my studies in biology, and eventually continue and get a biology degree—even though I was not eventually so much satisfied by those studies. Unfortunately, universities are not always the motivating, inspirational, thought-provoking environment one wishes them to be. But the important point is that my decisions to do undergraduate studies in biology made a difference. It was unpredictable, as nobody could have known in advance in which of the university departments that I had mentioned in my application I would end up being accepted. This depended not only on my own score but also on the scores of all the other candidates; I happened to be among the ninety who were qualified for the department of biology in Athens, and I was accepted. Once this happened, it thereafter affected my professional life.

Interestingly, not only my professional life, including writing this book, but also my personal life was influenced by my decision to study biology. It was because of my connection to the department of biology in

Athens that I met my wife, best friend, and companion in life, Katerina, who also spent some time in that department even though she did most of her studies in Paris. Whereas I had already completed my undergraduate studies in biology at that point, Katerina was completing her own undergraduate studies in Athens. After several years in Paris, she decided to come back home and complete her studies there in order to figure out what she would do next. Thus, she was attending classes at the department of biology in Athens, whereas I was not as I had already graduated. Meeting her was an event totally unpredictable, as we met through a person who had also studied at the same department and who was going there regularly at the time, whom I had only met twice before (another contingency: I came to know him because he happened to do his military service under my father), and to whom Katerina happened to talk for the first time on the same day that she also met me (because he and I had already planned to meet and talk shop and she wanted to learn more about job opportunities in Greece)! Katerina and I have been together ever since. This has definitely been the most critical event of my life since then, as it has influenced all the subsequent ones—including, above all, the birth of our children, Mirka and Giorgos. Therefore, I dedicate this book to Katerina for being the center of the most important turning point of my life, which has influenced all the subsequent ones that we have lived through together.

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My career as a biology teacher and educator has focused on helping students at all levels, from kindergarten to teacher training programs, acquire a rational and authentic view of life. My students, and their conceptions, have inspired and motivated me to write books, hopefully rigorous and accessible ones, which would help any interested reader understand biological phenomena and the related concepts. It is certainly no coincidence that my two previous books are titled *Understanding Evolution* and *Making Sense of Genes*; unavoidably, the present book shares some of the insights of those two books. Therefore, I am grateful to my former students for being a source of inspiration and motivation. I hope that the present book, which is intended for any thoughtful lay persons interested in biology, will sufficiently explain basic phenomena and share with them my own understanding of life.

I am indebted to John Beatty for his work that has been an inspiration for this book. It was back in 2007, when I had just finished my doctoral dissertation on evolution education, that, while we did not know each other, I just contacted him and proposed to meet him and talk. His

landmark paper, "Replaying Life's Tape," had recently been published and I had so much I wanted to discuss with him. I thus visited Vancouver, after a conference at Calgary, and John—one of the nicest people you can ever meet—was not only a great host but also an amazing discussant. It was then that I mentioned to him for the first time the idea about writing a book on contingency. His initial encouragement made me determined to write it. And I am happy that you are now holding it in your hands.

I am also indebted to Jonathan Losos, who graciously sent me a copy of his magnificent book *Improbable Destinies*, which was approaching publication as I was finishing writing the present book; as well as to Bernard Wood, who kindly provided me with figure 16.1 and useful essays related to that. Finally, I am very grateful to Francisco Ayala, Henry Gee, Alan Love, Kevin McCain, Alessandro Minelli, Ronald Numbers, Gregory Radick, Michael Ruse, and Elliott Sober for their comments and suggestions on the manuscript's earlier versions.

Last but not least, I am always grateful to my family, Katerina, Mirka, Giorgos, who bear with me while I am reading or writing or discussing my new book project at home. Writing will always be a hobby for me, even if I ever end up doing it as my main job. Thus, whereas other fathers and husbands deal with the garden or watch sports programs on TV while at home, I am reading and writing for hobby—it is not that bad, is it? Therefore, my wife and children do not miss me, but there must certainly be some other things we could have done together during those book-devoted hours. Lost hours are lost forever, but I hope that one day they may read this book and feel that it was worth the time and effort.

Introduction

CRITICAL EVENTS AND HISTORICAL OUTCOMES

One may have good reasons to worry that the public, broadly construed,[1] holds unscientific views about several aspects of human life. For instance, 42 percent of Americans believe that people are born homosexual, a percentage that has increased significantly since 1977, whereas more than half the people in Canada and Great Britain seem to think the same.[2] It has also been found that approximately one in four people in the United States, Canada, and Great Britain believe that the position of the stars and planets can affect their lives.[3] Finally, polls since 1982 until very recently show that over 40 percent of Americans accept the idea that God has somehow created humans in their present form.[4] There is also academic research suggesting that people tend to perceive evolution as a purposeful process, as well as believe that genes determine our traits and disease.[5] These, and other, findings support the conclusion that unscientific notions are rather widespread, although one should always be cautious about the possible interpretations of research findings about public opinion.[6]

What is common in all these views? One common aspect is the idea of determinism. People think that genes, or something else innate, determine traits, disease, and even behaviors (such as homosexuality), whereas we know that in most cases these are the outcome of complex interaction between genes and environment; people think that the stars determine our lives, even though the stars are too far to have any empirically measurable effect on us; and people think that God determines how we are and look, even though we exhibit so many features that would make any designer feel

embarrassed. Another common aspect of these views is the idea that in all of these cases there is a goal, which could be the outcome of purpose, intention, or design. When people think that genes, stars, or God determine our features and/or aspects of our lives, the underlying assumption is that there is some underlying plan toward some specified end point. However, a close look at the conclusions of research in developmental biology, human history, and evolutionary biology show that the course and outcomes of life are not predetermined based on some kind of plan, but rather that they can be influenced by particular combinations of critical events.

Let me clarify the terms I am using throughout the book. There are three closely related concepts (the first two are often considered synonyms), but they are distinct: *fate*, *destiny*, and *design*. Historically, *fate* and *destiny* have been defined in a variety of ways. However, fate is a concept that denotes that there are several aspects of our lives that we do not choose and do not control. We did not choose our parents or our biological characteristics, for instance. There are indeed some features that we are predisposed to have, such as having two eyes and two ears, or two legs and two arms. We do not anticipate human development to result in wings or beaks. It is only in this sense that a kind of developmental fate is conceivable. However, the impact of fate in our biology is sometimes exaggerated in the minds of people, resulting in the conception that I describe as *genetic fatalism*.[7] This view is explored in chapter 2, and part 2 of the present book provides concrete examples that challenge it.

Destiny is a concept that denotes that one can foresee future outcomes by evaluating particular elements that are already present or that have been present in the past. Based on these, one can make a projection to the future and imagine future outcomes, by envisioning what one could become based on what one already is. For instance, one may predict that a child who is extremely intelligent and has a great interest for nature is destined to become a great scientist. Or that someone who has a talent in music or arts is destined to become a musician or an artist. For some people believing in astrology, even the day when one was born

is informative for what will happen in the future. The difference with fate is that one's destiny cannot be just realized without effort and decisions. However, the idea of destiny is often misconstrued by people, who do not realize the impact of events within and outside our control and who think as if destiny is a predetermined outcome that will emerge one way or the other. This view is explored in chapter 3, and part 3 provides concrete examples that challenge it.

Finally, design is the idea that the world as we see it is the intentional work of a conscious, intelligent agent (usually God, however conceived) who designed it purposefully. As a result of this design, the physical world has all the properties that are necessary for the emergence of life. A related idea is that the universe also has all of those conditions that are necessary for the emergence of sentient beings such as ourselves, so that our presence in this world was inevitable under these conditions. Some people also claim that organisms exhibit such an enormous complexity in their structures and functions so that the most plausible explanation is that they were specially created and intelligently designed by God. This central idea here is that the complexity of organisms is so enormous that their emergence through natural processes is simply inconceivable; therefore, according to this view, organisms can only have been designed by an intentional and intelligent agent. This view is explored in chapter 4, and part 4 provides concrete examples that challenge it.[8]

In the present book I argue that genetic fatalism, destiny, and intelligent design are insufficient and illegitimate accounts for human development, human life, and human evolution. In all cases, outcomes are better accounted for by considering robust processes (developmental, historical, and evolutionary), as well as critical events that affected which one of several possible directions these processes took. To support this argument, I draw on published research that should nevertheless be considered as a representative and indicative sample of huge bodies of research, rather than an exhaustive account. I focus on studies reporting academic research, and in all cases I am citing research articles that I find indicative

of the respective findings and relevant to the argument I am developing in this book. This is especially important to keep in mind both about the research about the conceptions that people hold presented in the first part of the book, and about the research involving organisms, DNA molecules, fossils, and so on presented in the rest of the book.

In all cases, there are particular limitations that relate both to the object of the analysis itself and to the methods used. These limitations usually have an impact on the data obtained, and this should be taken into account in how these data are interpreted. This is especially important for the first part of the book, which presents research on human conceptions. As some researchers nicely put it, most people in the world are not WEIRD: Western, Educated, Industrialized, Rich, and Democratic. Yet this is the kind of people involved in much of the research presented in the first part of the present book (mostly from Europe and North America; the country in which a study took place is specified each time). The fact that the research that I present mostly comes from Europe and North America may be interesting to many of the readers of this book because they may also come from those parts of the world. But at the same time, these people represent a minority of the people currently inhabiting our planet, about 12 percent of the total population according to an estimation,[9] and so one had better refrain from generalizing from this research. There are other specific problems relating, for instance, to extracting and analyzing DNA from fossils. Furthermore, researchers make any interpretations within particular theoretical frameworks that also need to be taken into account when one is considering their conclusions. All of these together produce evidence that supports, or not, particular hypotheses. Evidence becomes stronger only when there exist many studies in a field and researchers conduct robust meta-analyses in order to acquire a view of where the field as a whole is going.[10] Therefore, evidence is not something independent and absolutely objective, but depends on one's interpretation; it is, generally speaking, anything that can make a difference to what one is *justified* in believing.[11]

This being said, I should note that my main aim in this book is exactly to argue what the available empirical evidence makes us justified in believing about life. As I have already mentioned, robust developmental, historical, and evolutionary processes produce life outcomes. However, the details of these outcomes depend on particular critical events and are in no way predetermined. As I show in parts 2, 3, and 4, the outcomes of human development, human life, and human evolution are what they are because of particular critical events with particular outcomes in the context of broader natural processes; they are not the predetermined outcomes of fate, destiny, or design. This entails that the related beliefs that I present in part 1 are largely unjustified. Therefore, my aim in this book is to make readers appreciate the impact of critical events in life, against any notion of design, goal, or purpose.

In particular, I draw on developmental biology, history of biology, and evolutionary biology to show that human development, human life, and human evolution have a common underlying principle: *outcomes are not predetermined but are shaped by critical events*. Human development, life, and evolution are historical processes: they are sequences of successive events that are unique in space and time; that is, they took place at a certain time in a certain place—not anywhere, anytime (the philosophical term for this is that they are "spatiotemporally" unique). Thus, critical events can influence the course of the respective processes and make a difference in which one of several possible outcomes will materialize; which one this will be is previously unpredictable, but once it occurs there is a causal dependence of the future on that. We tend to think in terms of design and intentions because we usually consider only the actual outcomes but not the unrealized or currently nonexistent ones. This entails that we try to explain the outcomes in hindsight based on what we know that happened, and therefore the actual outcomes seem to us to be natural, predetermined, and even inevitable. However, the outcomes of human development, life, and evolution are neither predetermined nor entirely random; they are historically contingent.

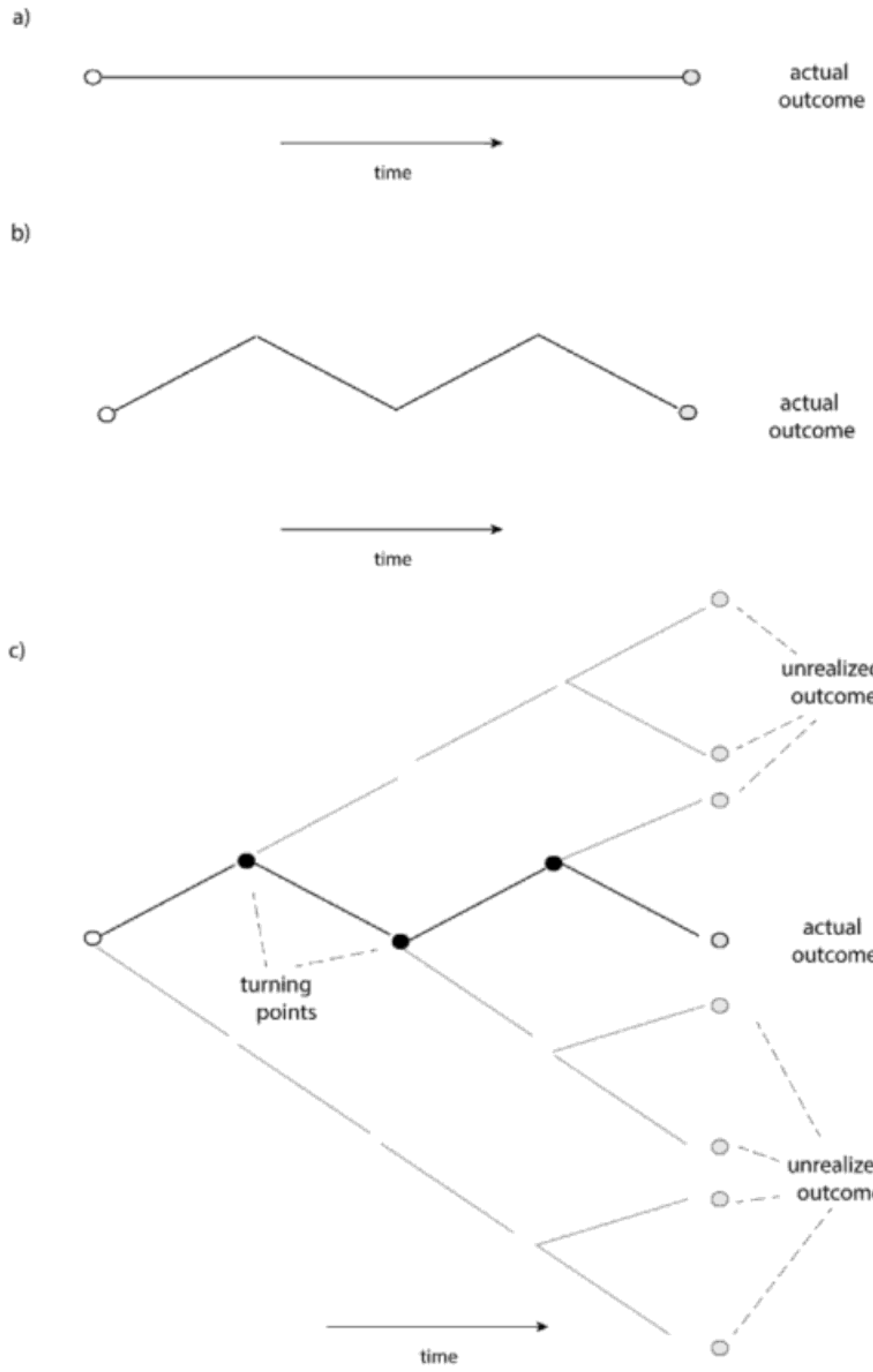

Figure I.1. The sequences of events that we usually tend to perceive as being straight lines (a) are in fact not (b). In contrast, they are part of a larger ensemble of possible but unrealized sequences of events (c).

Let us explore the problem of hindsight a bit more. A main problem is that we tend to perceive outcomes as the terminal points of straight, linear sequences of events (figure I.1[a]). But, more often than not, things are not like this. We often fail to realize that the sequence of events that we are aware of may not proceed in a straight line but instead follow an indirect path (figure I.1[b]). Most important, we fail to realize that in parallel with the actual sequence of events, there were other possible sequences that never occurred. If that had been the case, they could have led to other outcomes. In other words, we fail to see that at certain points there were more than one possible outcome, and that critical events led to one or the other direction thus influencing which of the possible paths was actually taken. These points are the **turning points** that are the focus of the present book (figure I.1[c]). The sequence of events, of which historical processes consist, should be perceived as depicted in figure I.1(c) and not as in I.1(a).

Thirty years ago, paleontologist and prolific author Stephen Jay Gould wrote a book-length account of the significance of these turning points and of the impact of critical events on historical outcomes. That book was *Wonderful Life*, and the central concept therein was contingency, defined as the "affirmation of control by immediate events over destiny."[12] To illustrate the idea of contingency, Gould used the metaphor of the cassette tape: "You press the rewind button and, making sure you thoroughly erase everything that actually happened, go back to any time and place in the past . . . Then let the tape run again and see if the repetition looks at all like the original." If each replay resembled life's actual sequence of events, then one could conclude that whatever occurred somehow had to occur.[13] But this would not be the case, according to Gould, as "any replay of the tape would lead evolution down a pathway radically different from the road actually taken."[14] In his book, Gould focused on the findings of the Burgess Shale formation, a fossil-rich deposit in Canada with an exceptional preservation of soft tissues of animals. In this set of fossils one could see the details of organisms soon after the so-called Cambrian

explosion some 570 million years ago, which was characterized by an enormous variation in forms and paved the way for the evolution of all major groups of multicellular animals. Gould concluded that the Burgess Shale fossils were an exemplar illustration of the impact of contingency in evolution. He thought that humans were no exception, and that we also are a contingent outcome of the history of life on Earth: "Replay the tape a million times from a Burgess beginning, and I doubt that anything like *Homo sapiens* would ever evolve again," Gould wrote.[15]

One of Gould's heroes in *Wonderful Life* was Simon Conway Morris. He was one of those who studied the Burgess Shale fossils and produced a new interpretation of the findings. However, he was not at all in agreement with Gould's conclusions about the impact of contingency on the evolution of life on Earth. In contrast, he later argued that what was important was the likelihood of the emergence of particular properties. Certain properties have appeared again and again in the evolution of life: "The tape of life, to use Gould's metaphor, can be run as many times as we like and in principle intelligence will surely emerge."[16] Conway Morris argued that several similar characteristics have independently evolved at different times in different lineages, a phenomenon called *convergence*. Similar characteristics can evolve independently in different lineages, if they are advantageous. One such example are the wings of birds and of bats, which serve the same function but are structurally different. In particular, the wings of birds consist of their fore-limbs whereas the wings of bats consist of their elongated digits that are connected via a webbed membrane of skin. According to Conway Morris, evolution is only possible in particular directions, not in any direction; in other words, the number of evolutionary pathways available to life are rather limited, not endless. At the same time, similar environmental pressures can favor particular advantageous characteristics and not others. In this sense, humans would have evolved on earth in some way or another.[17]

In the present book I consider the impact of contingency not only in human evolution but also in human life and development. Based on

these considerations, I argue (i) that the same principle, that critical events shape outcomes, underlies human development, human life, and human evolution, and (ii) that the same human intuitions preclude us from realizing this. Thus, whereas accounts for particular historical outcomes should cite particular antecedent conditions and highlight the impact of particular contingencies, we often tend to prefer accounts that present these outcomes as fulfilling some final end. A major characteristic of explanations of historical outcomes is that they are narrative explanations. Gould argued that the explanations of certain evolutionary outcomes (and I would add developmental and life outcomes as well) can take the form of a historical narrative. This would explicitly mention the contingencies of the antecedent states, which, had they been constituted in a different way, these outcomes would have not been brought about. These contingencies do not diminish the explanatory power of the narrative; a historical explanation can reach the same level of confidence as any physical explanation under invariant laws of nature, such as those in physics, insofar as enough details about the antecedent states are available in order to understand their causal relation to the observed outcome.[18] This means that we can adequately explain outcomes of historical processes such as human development, life, and evolution insofar as we have enough information about the antecedent conditions and the critical events that brought about these outcomes. Of course, this information is not always available.

Philosopher John Beatty has carefully and diligently analyzed the evolutionary contingency thesis and has distinguished between two versions, which Gould himself did not clearly distinguish: unpredictability and causal dependence. In my account in the present book, I consider these as two complementary aspects of contingency and not as two different versions. Indeed, Beatty himself noted that "we might even think of them as complementary components of a combined interpretation, according to which: a historically contingent sequence of events is one in which the prior states are necessary or strongly necessary (causal-dependence

version), but insufficient (unpredictability version) to bring about the outcome."[19] Let us consider these two aspects of contingency in more detail, by means of an illustration. Imagine that once an event A occurs, there are two possible outcomes: B and C. Whether it will be B or C that will occur after A is previously unpredictable; B and C could be equally probable, or one of them might be more probable than the other. In either case, insofar as one cannot tell in advance which one of them will actually occur after A, both B and C are contingent *per se*. Assuming that event B occurred, it was neither necessary nor bound to occur (this is the unpredictability aspect of contingency). Now, subsequent events B1 and B2 are contingent *upon* B, meaning that their occurrence depended on the occurrence of B. Assuming that it was B2 that actually occurred, its occurrence causally depended on whether or not B occurred—because it would not have occurred if B had not previously occurred (this is the causal dependence aspect of contingency) (see figure I.2). In the same sense, event C was contingent *per se*, but did not actually occur; neither did C1 nor C2 occur, because they were both contingent *upon* C. Therefore, events like B are critical because they may determine which of several possible paths will be followed. Such events that are *contingent per se*, and that subsequent events are *contingent upon* them, are called **turning points**.[20] In the present book I argue that narrative explanations are appropriate for explaining the outcomes of human development, human life, and human evolution, and that turning points are central in these explanations. I also explain why we should not perceive sequences of events such as A-B-B2 as predetermined or inevitable, and that we ought to also consider the possible but unrealized outcomes such as B1, C, C1, C2 (figure I.2).

Let us consider a more concrete example of a turning point, by analogy with a simple physical process. Imagine that you release a light-gray ball on a plane from which there are three possible routes: A, B, and C, each of which leads to the respective endpoint a, b, and c. These three routes are equally probable to follow, because the plane is designed and constructed in such a way that does not bias the direction a ball will take. Imagine now

Figure I.2. An illustration of turning points. Assuming that the actual sequence of events was A-B-B2, B is a turning point because it was *contingent per se* (C and not B might have occurred—unpredictability aspect of contingency) and subsequent events were *contingent upon* it (B2 occurred only because B occurred earlier—causal dependence aspect of contingency). The problem is that, intuitively, we tend to see only the historical sequence A-B-B2 and to overlook the possible but unrealized outcomes (B1, C1, C2).

that at each of these endpoints there is a bucket full of paint: white in a, dark gray in b, and black in c. Finally, imagine that the ball will be completely painted as soon as it lands inside each of these buckets. Now here is the impact of contingency: whereas it is not possible to tell in advance

which of the three routes A, B, or C the ball will follow (unpredictability aspect), the color that the ball will have in the end (white, dark gray, or black) will entirely depend on the route taken, as a bucket with paint of a different color is found at the end of each route (causal dependence aspect). No matter how many times we do this experiment, it will always be impossible to predict which of the three routes the ball will take, and its color will always depend on the route taken (figure I.3). What is the critical factor? It is which one of the routes A, B, or C the ball will follow, which in turn depends on how it will be released on the plane and how it will roll on the plane until it reaches one of the holes that leads to one of the three routes. Taking any of the three routes A, B, C is *contingent per se*; and the color that the ball will eventually come to have will be *contingent upon* the route taken.

Processes like these are often used to illustrate the concept of randomness, which is relevant but which should be clearly distinguished from contingency. In statistics, a sequence of numbers is random if it is impossible to predict the successive values. Therefore, randomness is about unpredictability in a sequence of events. In the case of the balls in figure I.3, we can say that which route the ball will follow is entirely random. What this means is that if you release three balls consecutively on the plane, you cannot tell in advance what the sequence of routes taken will be. There are twenty-seven such possible combinations (we have three objects combined in groups of three, so the possible sequences are 3^3, or $3 \times 3 \times 3 = 27$), which are presented in table I.1. The three balls could take each a different route; two balls could take the same route; or all three balls could take the same route. Now, before you have a look at table I.1, let's address the question: If you performed the experiment of releasing the three balls six times, which of the twenty-seven possible outcomes (e.g., A,B,C; B,C,A; etc.) would be more probable? You can write down your guessed path for each of the six drops: (1) _____ (2) _____ (3) _____ (4) _____ (5) _____ (6) _____.

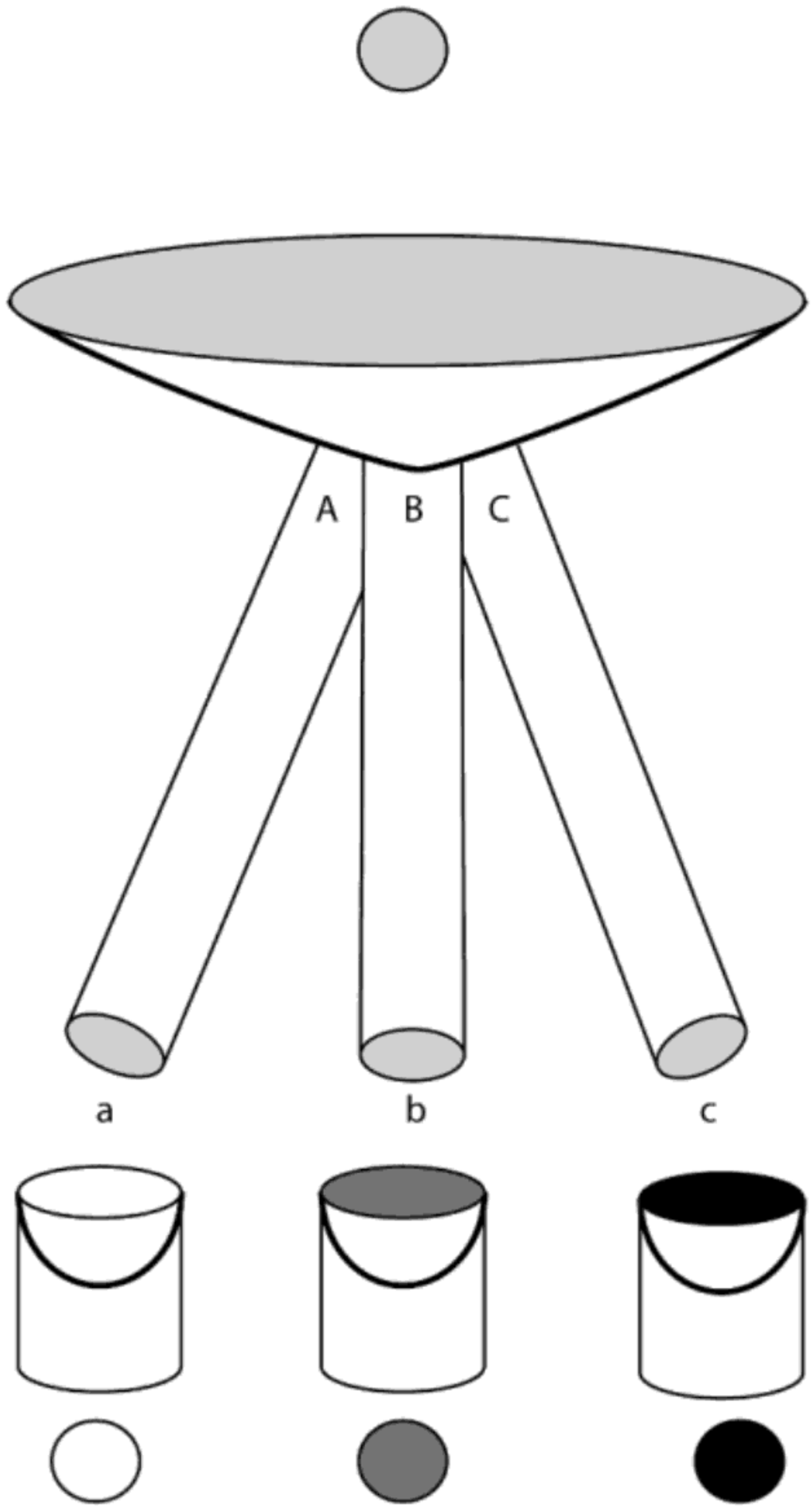

Figure I.3. If we release the ball on the plane, we cannot predict which of the three routes (A, B, C) it will take (unpredictability aspect of contingency); but the color it will come to have (white, dark gray, black) will depend on the route actually taken (causal dependence aspect of contingency).

All balls taking different routes	Two balls taking the same route		All balls taking the same route
ABC	AAB	CCA	AAA
ACB	AAC	CBB	BBB
BAC	ABB	CAA	CCC
BCA	ACC	ABA	
CBA	BBA	ACA	
CAB	BBC	BAB	
	BAA	BCB	
	BCC	CAC	
	CCB	CBC	

Table I.1. The twenty-seven possible combinations of routes taken when three balls are released consecutively on the plane of figure I.3. Each letter corresponds to the route taken by a ball. In all cases, the first letter corresponds to the route taken by the ball that was released first; the second letter to the route taken by the ball that was released second; and the third letter to the route taken by the ball that was released third.

So, what do you think? If you have mostly written the combinations in the left column, having thought that it is more probable for the three balls to take different routes because each route has the same probability . . . I am sorry, you are wrong![21] It is actually more probable that two of the balls will follow the same route. To put it simply, there are six different ways that each of the three balls can take different routes, but eighteen possible ways of two balls taking the same route.[22]

Now when it comes to historical processes like development, life, and evolution, the outcomes are not totally random but are biased in a sense, because they depend on what has happened before.[23] For example, if the apparatus was redesigned such that route C was possible only after going through route B, then the probabilities for taking each of these routes would not be independent—because the two events are not independent. Only those balls that would take route B would also take route C (see figure I.4). This also nicely illustrates the idea of causal dependence: a ball can take route C only if it also takes route B; but a ball that takes route A

will never take route C. What I want to note here is that the outcomes of historical processes are not entirely independent, and we cannot simply calculate their probability through the probabilities of the various events. An event may generally be of low probability, but it is almost certain once another event takes place. This means that in historical processes, which are sequences of events in which one brings about the other, we need to consider the probabilities of all the evens in a sequence in order to estimate or explain the probability of the final outcome.

To sum up: critical events shape outcomes by influencing the direction of a process toward a particular path among several possible paths. Which of these will be followed is previously unpredictable, but once taken the outcome depends on it. In *Turning Points*, I argue that this causal dependence often makes us in hindsight perceive outcomes in our development, lives, and evolution as inevitable. This we do because in hindsight we selectively pick up past events and use them to explain these outcomes as inevitable, overlooking the impact of critical events that were turning points. Yet, I argue, many of these outcomes were evitable, because they were causally dependent upon unpredictable critical events. Our development, life, and evolution could have thus taken other paths, resulting in different, alternative outcomes than those that actually occurred.

These alternative outcomes are often described as counterfactuals. Counterfactuals can be defined as "alternative versions of the past in which one alteration in the timeline leads to a different outcome from the one we know actually occurred."[24] Imagining these alternatives versions of the past that could bring about different outcomes is crucial for realizing the importance of turning points. One does not need to figure out exactly what these different outcomes could be, but only consider their plausibility. One might think that imagining and describing alternative worlds are appropriate for novels and for books on science fiction, as we cannot really know—but only imagine—how these alternative worlds could have been. This is indeed true for many cases. However, there are several cases in which this is possible. For instance, consider the personal

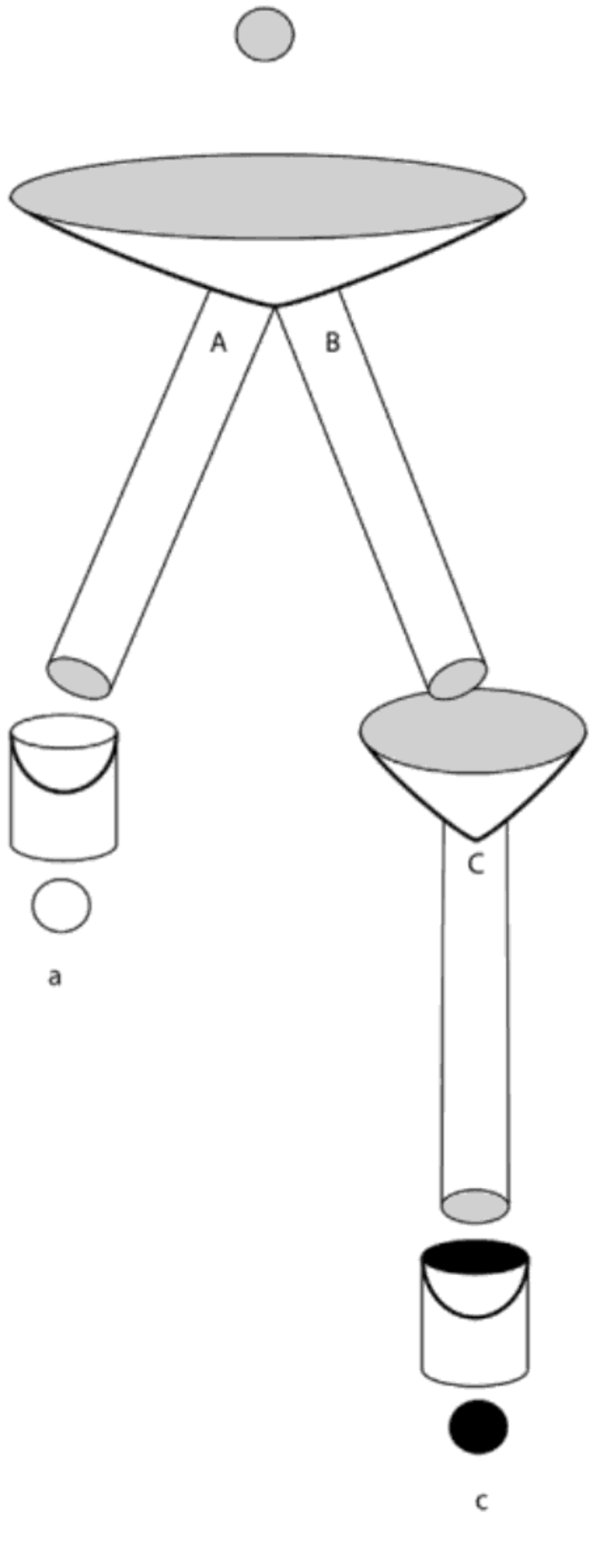

Figure I.4. If we release the ball on the plane, we cannot predict which of the two routes (A or B) it will take (unpredictability aspect of contingency); but the color it will come to have (white or black) will depend on the route taken, and it can only take route C after having taken route B (causal dependence aspect of contingency).

story that I described in the preface. Had my father died in July 1974, my brother would not have been born, and this is a counterfactual outcome that can be identified with certainty. I am also certain that my whole life would have been a lot worse than what it was, had I grew up without my father around, whatever my mother and the rest of the family could have done for me. But this is a counterfactual outcome that I can identify with less certainty, because I cannot really know. For instance, my mother could have raised me with love and affection that would have compensated the love and affection that my father actually provided me with. I seriously doubt this, as the loss of my father would probably have stigmatized my life forever, but I accept that in this case I cannot really know. However, the important issue here is that, in hindsight, I do not take for granted that my father lived. I am especially sensitive to the fact that his survival was contingent *per se*, and the lives of my brother, our mother, and myself were contingent *upon* that.

My main aim in *Turning Points* is to highlight the contingent character of actual sequences of events that some people take for granted in hindsight. It is the certainty of hindsight that actually blinds us in seeing the possibility of counterfactual outcomes. The objective, therefore, is to liberate ourselves from hindsight and try to see past events and historical processes as open to various, unpredictable possible futures. Whatever these outcomes could be, considering their possibility and plausibility can help us grasp the importance of turning points in the context of robust developmental, historical, and evolutionary processes. To achieve this, we need to adopt a new perspective that is free from hindsight and that considers events in the context in which they actually occurred, and not after they did. It is only then that we can begin to consider that there could be alternative possible paths (see figure I.5). Therefore, my goal is to help you replace the perspective in figure I.5a with that in figure I.5b—or to facilitate you to help others do this. In doing so, you might come to see more clearly that the actual outcome has been what it is because of the path taken at particular turning points, whatever the possible alterna-

tive outcomes could have been. You do not need to know the details of these alternative outcomes; you only need to recognize that alternative outcomes were possible.

A relevant distinction is that between multifinality and equifinality. Multifinality is the idea that an outcome is a part of a complex causal process, in which different antecedent conditions could produce different outcomes. Therefore, an outcome that actually took place might have not taken place under different antecedent conditions. For instance, as I also described in the preface, I met my wife because she was invited by a person I would be meeting on that day to join us, and she accepted. If she had not been invited, or if she had not accepted, we might have never met. As a result, we would not have gotten married and our family would not have existed. In contrast, equifinality is the idea that an outcome is somehow fixed and meant to happen. Therefore, different antecedent conditions are equally likely to produce the same outcome. For instance, according to this view, if my wife and I had not met on the particular day that we actually met, we would have probably met at some other time and eventually we would get married and start our family. When we look at outcomes with hindsight, equifinality may seem intuitive because we may be able to think about several antecedent conditions that might lead to the same outcome—in my example, having that person invite my wife to join us at some other time, or re-invite her even though she declined the first time, and have her join us then. When we take a certain outcome as given, it is possible for us to think of various alternative conditions that might have led to that—for instance, thinking that because my wife and I had a common acquaintance, we would have met somehow. The problem is that in hindsight we take the actual outcomes as given, and we think that they would somehow have occurred anyway, and perhaps even consider them inevitable. But if we manage to liberate ourselves from hindsight and look at the events as they took place, we may realize that multifinality is more likely and that things might have easily turned out differently than how they actually did.

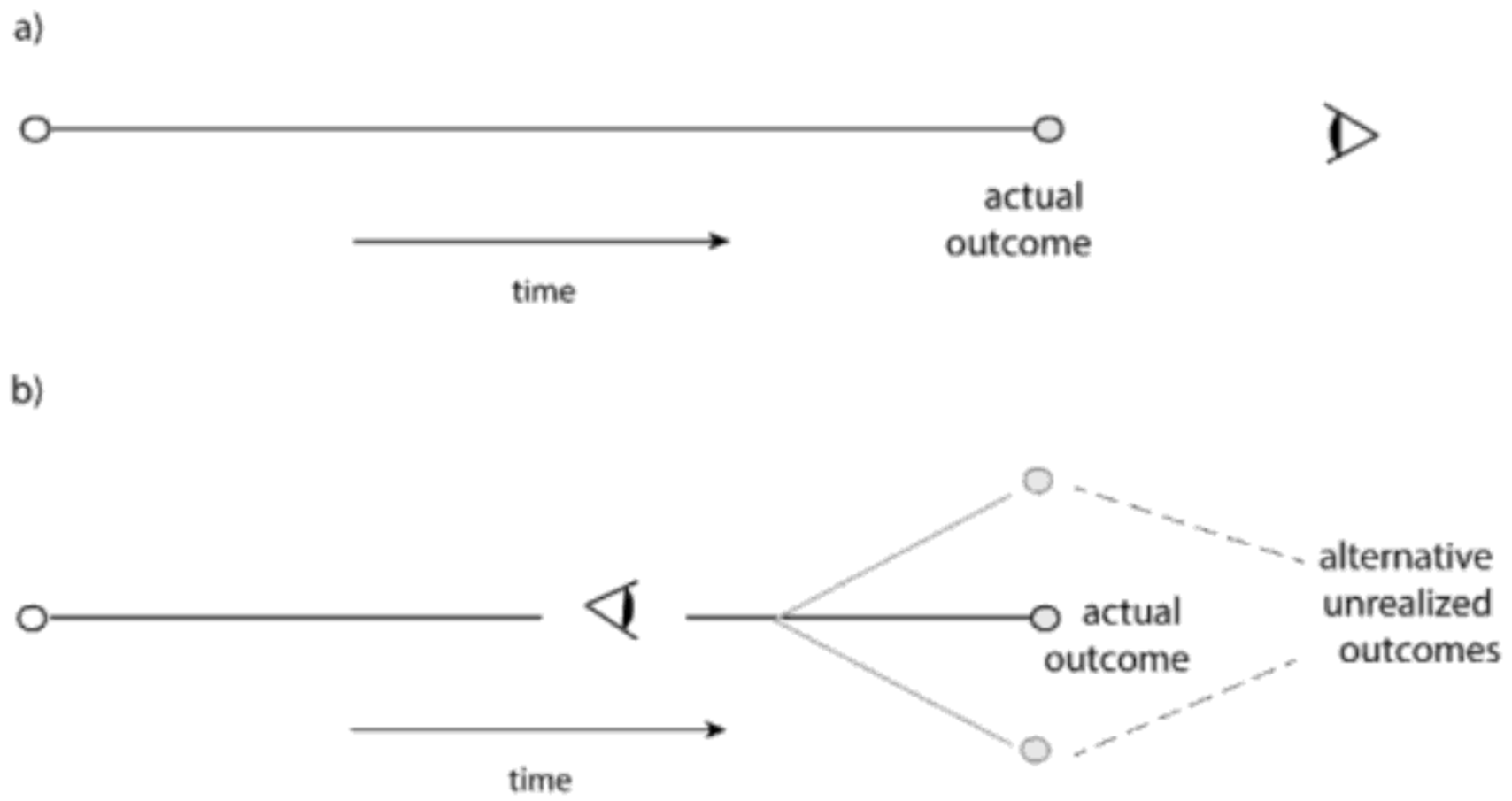

Figure I.5. (a) When we look at events with hindsight, after an event has occurred, we only look backward in time and only see the path actually taken and the actual outcome. Thus, we may think of this outcome as inevitable. (b) We need to imagine ourselves within the actual context of past events, before the actual outcome that we observe took place, in order to imagine the possible alternative, unrealized outcomes.

In part 1, I present prevalent conceptions about fate, destiny, and intelligent design, which act as obstacles to laypeople's understanding of the living world. These obstacles are then challenged in the subsequent parts 2, 3, and 4. Researchers in psychology, science education, and the public understanding of science have concluded that several unscientific conceptions are quite widespread among people. These notions share the common underlying idea that external or internal factors, which humans are entirely unable to control, determine the outcomes in human development, life, and evolution. In this sense, these outcomes may be considered predetermined and inevitable. Interestingly, this idea feels very intuitive to humans. In part 1, I offer evidence that these unscientific conceptions are quite prevalent, and I explain how and why people intuitively respond or react to tasks used in research. In many cases, I also provide you, the reader, with the opportunity to take these tasks before reading further,

in order for you to reflect upon what you think—or what you think that you think.

One important aspect of human development is that it is characterized by both robustness (individuals exhibit the general characteristics of a species irrespective of the environment they live in) and plasticity (individuals of the same species with the same genotype may exhibit different phenotypes depending on local conditions).[25] Robustness and plasticity are complementary aspects of development, yet we tend to pay more attention to the former than to the latter. However, the outcome of development depends on both our genome and critical events during our development. Based on the cases discussed in the second part of the book, I explain why genetic fatalism cannot account for human development and for the origins of traits and disease. The characteristics of humans are the outcome of critical events that took place during their development. Whether one will be born at all, as well as which traits one will exhibit depends on various critical events and is not predetermined in one's genes. Besides highlighting the criticality of reproductive and developmental events, another aim I have in part 2 is to teach some basic biology. Most people should remember learning about mitosis and meiosis at school, however I guess that many of them must have wondered at that time why they needed to learn this stuff. As I show, many events that occur during meiosis, the division leading to the production of spermatozoa (sperm) and ova (egg), have a big impact on how humans develop—if they develop at all. Mitosis, the division by which cells proliferate and an embryo grows, can also have a big impact on its development.

In the third part I aim at showing that there is no inevitable destiny in life but people do whatever they do because of critical events and their decisions and actions related to them. As an example, I show that important advancements in our understanding of life were not waiting to be made, and those who made them were not destined in any way to do so. The contributions of particular individuals made a difference, and these in turn were contingent on the conditions under which these individuals

lived and worked, and on particular critical events. Charles Darwin's life and theory serve as a case study here. Darwin's theory had the form and content it had in *On the Origin of Species* and it was published in 1859 because of particular turning points: the *Beagle* voyage between 1831 and 1836; Darwin's reading of Thomas Malthus in 1838; the publications and the public reception of the *Vestiges of the Natural History of Creation* in 1844; and Darwin's reception of the letter by Wallace outlining his own theory in 1858. Darwin's theory could have been published in a different form, had it been published earlier or later than 1859. However, particular turning points led to the publication of *On the Origin of Species*, which was far from inevitable. I must note that these are not the only turning points in Darwin's life but the ones that my reading, and interpretation, of his autobiography made me conclude that he considered as the most important ones. I must note, also, at this point that I used the development of Darwin's theory and not a broad historical event—such as how World War I started, to take a classic example—because it is at the individual level that the impact of contingencies becomes clearer.

Finally, in part 4 I show the impact of contingent events on human evolution. Based on the cases discussed in that part, I explain why intelligent design cannot account for the emergence of humans. Human features were not designed but are the outcome of evolutionary processes. The distinctive characteristics of humans discussed in those chapters are the outcome of critical events that took place during human evolution. How we have evolved to be was far from inevitable and the outcome of contingent events. This entails that neither our presence in this world was inevitable. Contrary to the view that the conditions in our world have been appropriate so that life could arise (and/or evolve), I argue that life has evolved because the conditions have been those that allowed this to happen. Had the conditions been different, it is possible that life as we know it and humans might have never existed.

The present book is intended for the general reader who is interested in biology and in understanding how turning points have made us who

we are. It brings together research from psychology, science education, developmental biology, history of biology, and evolutionary biology to show that—contrary to popular, intuitive views such as genetic fatalism, destiny, and intelligent design—it is critical events that shape outcomes. My aim is to show that whereas people tend to intuitively perceive purpose and design in nature, contingency plays an important role in human development, life, and evolution. For this purpose, scientific evidence is used to show why the idea of purpose and design in human development, life, and evolution is implausible. This is presented after a review of the evidence that several people do indeed tend to have such beliefs. Finally, I also aim at making the general reader familiar with some fundamental knowledge and contemporary research on the respective fields.

I should note that I do not assume that all readers think that there is purpose and design in nature, although this is the case for many people. However, I have seen that even well-informed people find hard to accept that there is no design and no purpose in nature because such a view conflicts with their intuitions. Therefore, a main target of the present book is the intuitiveness of this idea. Those who see plan and purpose in nature but are open to reconsidering their own views might find this book useful for reflection. And those who do not see plan purpose in nature might find this book useful for getting arguments and evidence to help those who think otherwise to understand why this might not be the case. I think that this is important because I have seen several people who believe in fate, destiny, and design both be passive and indecisive and accept events as they come, without ever trying to change anything. Of course, we cannot change our development and evolution; but if we appreciate the impact of contingencies, we might try to change our lives by at least refraining from holding unjustified beliefs.

I have focused, here, on humans in order to make this point easier to explain. Writing about human development, life, and evolution inevitably draws on examples that are "close to home," about which people have most likely wondered and which they might find easier to understand. In

addition, I think that this most likely makes the book more interesting; because it is about us! We, humans, are nothing more than a very recent and very short branch in the enormous web of life on Earth—an explicit disclosure from my part, if you think that I am being unnecessarily anthropocentric. Any such book about any such organism could be important, be interesting, and provide valid arguments for the role of critical events in development, life, and evolution. But understanding better the human condition is something that many of us have thought about—how many of you have sincerely wondered about the evolution, development, and lives of species such as *Daphnia* or *Drosophila*? My guess is very few of you. Therefore, I hope that my focus on humans, albeit a narrow one, has indeed made this book both intelligible and interesting to you. Because it is about you.

A final point. Many events can be unpredictable and have several possible outcomes, only one of which will materialize. In this sense, many events could qualify as turning points. This raises the question: are all these "real" turning points? If yes, then are there turning points that are more important than others? In my view, the criteria for identifying a "real" turning point stem from the definition of a turning point itself. I defined a turning point as an event that is unpredictable (contingent *per se*, because other events were also possible but it was that and not the others that occurred) and that has significant consequences (future outcomes are contingent *upon* it, because that event was necessary for the subsequent evens to occur). Many events are unpredictable but do not have significant consequences; also, many events have significant consequences but are relatively predictable. A turning point is thus an event both that is unpredictable (in terms of whether and how it will occur) and that impacts what comes next (in the sense that the future will depend on how that event occurred). Whereas the criterion of unpredictability is more or less clear—something that one could not have foreseen—one might wonder about the criterion of significant impact. An unpredictable event becomes a turning point when its impact is significant, either

in terms of time (a long-term impact), or in terms of quality (because it narrowed down the potential features and thus shaped the outcome). The examples that I give in parts 2, 3, and 4 of this book have both of these features. I should note again that these are not the only turning points in human development, Darwin's life and publication of his theory, and human evolution. But I argue that all of these are genuine turning points that provide evidence that thinking in terms of fate, destiny, and intelligent design in unjustified.

Let us now explore this thinking in more detail.

Part 1

THE DESIGN STANCE

Chapter 1

"WHY X?": "IN ORDER TO Y"

Have you ever asked yourself why we have hearts? Most people would reply: "In order to pump blood." Many human characteristics seem to serve goals, and these goals look quite obvious in many cases. Why do we have legs? "In order to stand up and walk" is an answer that would make sense to most people. Why do we have opposable thumbs? "In order to grasp and handle objects," most people would also reply. And this can go on for any of our body parts and organs you can think of: brain, stomach, lungs, liver, to name a few. The roles of other characteristics may seem less obvious, but they also seem to be there. Why do we have eyebrows? "In order to prevent sweat from entering our eyes" is a plausible answer. Why do we have hair on our heads? "In order to keep our brain warm" is again a plausible answer. But if you think harder, it is not easy to assign goals to all characteristics. Why do we have toes? Why do men have nipples and facial hair? And so on. Perhaps there is a less obvious role in these cases, *but it must be there*, you may think. Otherwise, if they do not do anything, why would we have certain characteristics? In other words, why would characteristics that serve no use or purpose exist at all? You may have thought about questions like these in the past, and you may have arrived at certain answers like those above. In this chapter I invite you to forget for a moment your earlier conclusions and follow me on a foray into thinking about purpose and design in nature. Answers to such "Why X?" questions that explain the presence of a characteristic are considered explanations. Throughout the present book, I consider explanations as statements that identify the causes of a biological characteristic or phenomenon, that is, that provide an account for why it happened or

why it came to be. And when these explanations take an "in order to Y" form, they are described as teleological explanations (*teleological* means that their logic is based on the goal—*telos*—that they serve).[1]

The discussion about purpose and design in Western culture goes back more than two thousand years, at least back to Plato and Aristotle. Plato believed that the universe was created by a Divine Craftsman, the Demiurge (Creator). Plato considered the transfusion of the soul of the Demiurge into the universe as the final cause of its creation. This process had to take into account the actions of Need, the mythical equivalent of the properties of the structure of matter, which imposed constraints to the work of the Demiurge. Plato thus recognized two types of causes, which he viewed as interdependent and not in conflict. Therefore, the universe was an artifact that resulted from the purposeful and rational action of the Demiurge that had dominated over the irrational Need. This is a view of the world being "unnatural," in the sense that it is the product not of natural processes but that of a divine craftsman. Aristotle was a student of Plato who tried to answer questions about phenomena in organisms by looking for natural causes. He thus described four causes that acted in nature: the *efficient* cause, the *material* cause or *matter*, the *formal* cause or *form*, and the *final* cause; and he considered all four of them necessary for understanding. The classic illustration of these causes is with the example of a statue: (1) the *material* cause is the bronze of which the statue is made, which undergoes a change that results in the statue; (2) the *formal* cause is the shape of the statue, as the bronze is melted and used in order to acquire a particular shape; (3) the *efficient cause* is the knowledge that the craftsman implements to create the statue; and (4) the *final cause* is the goal for the fulfillment of which the whole process of the production of the statue is taking place. Even though the example of the statue might make one think that Aristotle thought in terms of design like Plato, this is not the case. For Aristotle, there were no external intentions, and the final causes served the maintenance of an organism. Thus, the final cause for the existence of an organ would be its

usefulness to the organism that possessed it and not, like Plato, the intentions of a divine designer.[2]

This outline of the Platonic and Aristotelian teleology encapsulates the essence of teleological explanations. On one hand, there is the view that teleology is external to the entity under discussion; the final ends are determined by a conscious, external agent who intentionally designs something with a purpose in mind. Details notwithstanding, this kind of external teleology can be illustrated with the barbs of barbed wires. Humans designed and created barbed wires in order to protect something that is of value to them. In this sense, the barbs of the barbed wire exist in order to fulfill a purpose that is external to the barbed wire itself. On the other hand, there is the view that teleology is internal to the entity under discussion; the final ends are determined by the usefulness of particular features for the entity that bears them itself, and not by any conscious, external, intentional agent. Details notwithstanding, this kind of internal teleology can be illustrated with the thorns of roses. These protect the roses themselves, for instance, from animals that might want to eat them. In this sense, the thorns of roses exist in order to fulfill a purpose that is internal to them, their survival, and not determined by any external agent. Therefore, we can state that both barbs and thorns exist for a purpose, but this purpose is different: it is external in the case of barbs and internal in the case of thorns. These are two main types of teleological explanations. In this chapter, as well as throughout the whole of part 1, I explore the intuitiveness of teleological explanations in various contexts by presenting the findings of studies about how humans rely on such kinds of explanations in order to account for the development and evolution of biological traits, as well as of life outcomes. In this chapter, I first present research about the prevalence of teleological explanations in general. Then, in the subsequent chapters, I present explanations related to human development, human life, and human evolution. I should note that I do not always get into the details of whether the teleological explanations under discussion are of the "external" or the "internal" type.