DEVELOPING MATHEMATICS AND SCIENCE ANEW

INTEGRATING MIND INTO SCIENTIFIC VIEW OF THE UNIVERSE

Volume I

Chapters 1 – 3 plus preliminary outline of all chapters from both volumes

(no other full chapters will be available here)

This book proposal is being continuously, often daily, modified, so rely on the latest version at http://www.cs.unb.ca/~goldfarb/BOOK.pdf

May 25, 2011

© Lev Goldfarb

All comments are gratefully appreciated (goldfarb ‘at’ unb ‘dot’ ca)
# Contents

1. **Introduction: The pressing need to start our scientific journey afresh** 3  
   1.1 The language of science: Scientific formalism 3  
   1.2 The old mind-matter split is costing us now much more than we can afford 8  
   1.3 Original motivation for the development of the new formalism 11  
   1.4 The basic idea of the proposed structural representation 13  
   1.5 Induction and structural representation: What is the connection? 23  
   1.6 Informational organization of Nature 26  
   1.7 The precedence of temporal representation over spatial in the new formalism 31  
   1.8 Some general points concerning ETS and the present state of science 33  

Notes 41  
Useful terms 44  
Basic points 46  

2. **A brief history of induction: What has been missing?** 50  
   2.1 Aristotle’s unsurpassed epistemological advance: The road to knowledge via induction 50  
   2.2 Francis Bacon and a superficial acceptance of his inductive methodology 53  
   2.3 Hume’s “Problem of Induction” 55  
   2.4 Mathematics and induction: Poincaré against Hilbert and logicians 56  
   2.5 The tragicomedy of induction in the last century 58  
   2.6 The unreasonable expectations of probability theory 63  
   2.7 Helmholtz’s insight and the lack of progress with concepts in today’s psychology 65  
   2.8 Some of the secondary relatives of induction: Abstraction, abduction, universals and particulars 67  
   2.9 The missing basic constituent of induction: What is a class? 68  
   2.10 The unsuitability of human and logical languages as well as numeric formalisms to deal with the concept of class 75  

Notes 77  
Useful terms 79  
Basic points 80  

3. **The temporal origin and the temporal axiomatic structure of natural numbers** 83  
   3.1 Before numbers: Counting and four stages in the development of natural numbers 83  
   3.2 The temporal origin of natural numbers and their modern axiomatic definition 84  
   3.3 The role of various geometric constructions in our culture and science 86  
   3.4 Conclusion: The origin of the historically inevitable displacement of the temporal by the spatial 87  

Notes 89  
Basic points 89
Chapter 1

Introduction: The pressing need to start our scientific journey afresh

... the profound conviction [is] that the foundations of science as a whole and of physics in particular, await their next great elucidations from the side of biology, and especially from the analysis of the sensations ...

[and that a new] science ... embracing both the organic and the inorganic shall interpret the facts that are common to the two departments.

Ernst Mach

... it is already clear that any correct theory of the relation between mind and body would radically transform our overall conception of the world and would require a new understanding of the phenomena now thought of as physical. Even though the manifestations of mind evident to us are local—they depend on our brains and similar organic structures—the general basis of this aspect of reality is not local, but must be presumed to inhere in the general constituents of the universe and the laws that govern them.

Thomas Nagel

One can best feel in dealing with living things how primitive physics still is.

Albert Einstein

1. The language of science: Scientific formalism

In this chapter I outline the main reasons why our science needs a fresh start. To this end, we begin with the most relevant yet both neglected and taken-for-granted issue of data representation in science. In particular, let us think about what we understand by “data” and how we collect it.

But first, thinking of the ubiquitous “data”, recall that the main distinctive characteristic of our sciences (and not only of them) is the unqualified reliance on numbers, measurement processes, and on the highly developed apparatus associated with the numeric language. It is this, never-challenged, scientific status of the numeric ‘language’ that I propose to reconsider, especially in light of the long-sought scientific vistas that its new, non-numeric, alternative discussed here should open for us.

Let us fix the term scientific, or representational, formalism for the basic form of data representation—that is, the chosen representation set (Fig. 1.1)—plus the accompanying formal apparatus. Such formalism is the compulsory ‘spectacles’ one must wear when doing science, in order to collect and process data. The main but taken-for-granted component of a scientific formalism is its representation set (Fig. 1.1): the set of abstract entities carefully constructed to represent, or stand for, the actual objects one is dealing with. (Note: “object” is always used in the most abstract sense, which includes “process”.) For us, it is important to generalize the present situation in science and assume that just mentioned “abstract entities” do not have to be of numeric origin only.
As we well know (Chap. 4–7), our science, so far, has relied on a single basic representational formalism, which is associated with the numeric measurement processes. I will call it, including its variations, the numeric formalism. In it, numbers and, later, a variety of numeric constructions—e.g. complex numbers, vectors, matrices—serve as related ‘parts’ of the above representation set, i.e. we represent actual objects by means of such kinds of numeric entities. In particular, we substitute for an actual object $O_j$ point $S_i$ from some “space” (Fig. 1.1), where the point is usually identified by its numeric coordinates, e.g. spatial position, size, speed, brightness, etc.

So, again, when viewing our present scientific enterprise as a whole, the tacit or taken-for-granted part is the absolute requirement to wear the ‘numeric glasses’ when engaged in it:

Our instruments of detection and measurement, which we have been trained to regard as refined extensions of our senses, are they not like loaded dice, charged as they are with preconceived notions concerning the very things which we are seeking to determine? Is not our scientific knowledge a colossal, even though unconscious, attempt to counterfeit by number the . . . world disclosed to our senses? [My italics]  

Our scientific and everyday lives are dominated by the questions “how much”, “how big”, “how small”, “how long”, “how far”, “how heavy”, etc. Indeed, little has changed since the time of Newton, when he declared: “God created everything by number, weight and measure”. Yet when we look at a tree or at a face, what draws our attention is their ‘individuality’. Historically, many sages have agreed that this ‘individuality’ (pattern) is of qualitative rather than of quantitative, or numeric, nature, where ‘quality’ and ‘quantity’ are often rightly considered to be antonyms. According to the new scientific point of view outlined in this book, our perception might actually be of non-numeric nature.

The ubiquitous numeric form of data representation, discussed in Chapter 6, was sanctioned during the so-called Scientific Revolution, mainly of the 17th–18th centuries. This “revolution” would have been unthinkable without the previous three centuries of the historically unprecedented general
cultural shift from qualitative to quantitative (numeric) perception in Western Europe (Chap. 4). The shift was even more impressive since it affected not only the economic activities and those related to the measurements of time and space—including the spread of mechanical clocks, marine charts, and double-entry bookkeeping—but also painting (perspective) and architecture. At the same time, the Scientific Revolution was the continuation of our many-millennia-old numeric history, especially of the taken-for-granted Greek scientific revolution discussed in Section 4.1. So one might say that the second Scientific Revolution (of the Early Modern period in Europe) built the numeric ‘train’, but the numeric ‘rails’ for it had been ready for a long time, right after the first, Greek, scientific revolution.

Given our very long and ‘pervasive’ numeric history, it is not surprising at all that until the advent of computers the very issue of unfamiliar, non-numeric, forms of object representation could not have arisen. But the wide applications of computers inevitably brought to the fore the general topic of object representation, particularly in the computer (and, unavoidably, in the mind).

In the main part of Volume I, I discuss the structure and the inherent—i.e. related to the formal structure—limitations of the numeric form of object representation (where $S_i$ in Fig. 1.1 is a point in some space). Such representations plus the scientific orientation on the spatial object motion in the 17th–18th centuries have shaped the development of mathematics, physics, and, presently, all data processing fields. I will argue that it is this ubiquitous, spatial (point-based), form of data representation that is responsible for a one-sided and progressively confusing view of Nature.

Historically, the use of numbers has been a predictably ever-expanding affair: from the temporal origin of natural numbers, discussed in Chapter 3, to counting, to measuring, and then to object representation (via numeric coordinates). Yet it is the latter that is the main culprit, and its roots can be traced to the, probably, inevitable shift from the temporal to the geometric, or spatial, considerations in the ancient measurement practices. I will argue that numbers were brought into the representational ‘business’ during the Scientific Revolution based on quite convenient at the time—but, as it presently emerges ‘immature’—spatial view of objects as composed of “points”. (And to this end, Aristotle’s more sophisticated view of objects had to be repudiated.)

We will also see in Chapter 3 that the natural number—both as it emerged pre-conceptually and as it is axiomatically treated—is a temporal concept (see Fig. 1.4). The original use of numbers for counting, driven by the emerging economic relations, was representationally neutral. But as the ‘sin’ of using numbers for representational purposes began to be exploited with a remarkable genius by the protagonists of the Scientific Revolution, numbers have since been ‘recruited’ to measure anything we fancied, including energy, productivity, and even happiness. The extension of natural to real numbers was motivated by applied geometric (again spatial) considerations—first, by the irrationality of $\sqrt{2}$ and later by the needs of calculus. As a result, the temporal origin of natural numbers was completely overridden by the spatial connotation of this, much larger, set. The time was also turned into an extra spatial dimension and hence, effectively and quite conveniently, emasculated (Chap. 5–9).

Today, we ran into serious conceptual difficulties in the hort of physics, in quantum mechanics, because a ‘discrete’ underlying reality is being forced into a continuous formalism, the only one we know. This situation merely exposes a purely calculational—or, increasingly, the famed “shut up and calculate” face of the numeric formalism. At the same time, as was argued by the late Czech-American philosopher of science Milič Čapek, the early discovery in the same quantum mechanics of quantum indeterminacy and quantum ‘fluctuations’ have also exposed the inadequacy of the
(numeric) conservation laws as well as of the basic physical concepts, e.g. energy, time, mass, moment. However, as we will discuss in the following sections, the limitations of the numeric representation came to the fore more recently, when we had to model the ‘intelligent’ information processing, and inductive processes in particular (see Section 3).

So the innocent ‘original sin’ of measurement has eventually turned into the measurement madness and has caught up with us even in science. Inevitably, it also contributed significantly to the erosion of our moral and social values (see the quotations in the next section) by severing our deep-seated primal ‘animistic’, or spiritual, bond with Nature and, more importantly, leaving cold emptiness in its place. As already Nietzsche allegorically, but quite somberly, diagnosed the situation, “God is dead”.

Yet at the onset of the Information Age, we are compelled to rethink the central role of numbers, numeric measurements, and of the spatial considerations in science. It appears that the informational considerations require us to shift from the numeric to a richer and more appropriate for that purpose structural object representation. Moreover, since the informational is our last scientific frontier, we should expect from the new form of data representation, from the very outset, some indication as to the source of spirituality in Nature that our science has been missing. These are the issues I have been thinking about and working on since the early 1980s: How can we move beyond our numeric formalism, and what will the Nature look like through the new, non-numeric, ‘spectacles’?

Incidentally, independent of information processing demands, the greatest expansion of our scientific horizon may also be achieved through the transition to a non-numeric form of representation: no fundamentally new form of data representation—no fundamentally new view of Nature. Indeed, what else can open up comparable new horizons? In other words, the most direct and powerful way to see the reality in a new light is to change the basic form of data representation in which all our data, including even (digital) images, is being collected, stored, and processed. Of course, the transition process can neither be attempted nor proceed in any historically familiar way.

Before discussing the new formalism—in which the result of ‘measurement’ is not a number—let us give it the name structural formalism, or structural representation. The adjective “structural” is supposed to suggest that each $S_i$ in the representation set (Fig. 1.1) is not the familiar point, or some unstructured and atemporal entity, but one formed by temporally linked units of informational nature (see Fig. 1.5). So the main idea is to assign to an object not the spatial entity “point” but the informational structure corresponding to the object’s formative history, event by event.

Specifically, taking into account the evolving nature of the Universe, I propose to understand the “structure” of an actual object $O_j$ (Fig. 1.1) as the object’s “formative structure”. This structure is supposed to capture the object’s formation process, or its “formative history”, comprised of temporally interconnected formative events—the above structured units. (As we shall see, each such informational unit-event also serves as the blueprint for its spatial counterpart, i.e. a spatial event that we usually observe.) Obviously, any object in Nature, including the Universe itself, is the result of the ‘physical’ events responsible for its formation, but the possible informational origin (and structure) of the events have not been considered. The concept of structured “event” will be given precise meaning.

From the perspective of an ‘intelligent’ agent—who does not have access to an object’s complete formative structure—in order to construct the (subjective) representation $S_i$ of an object $O_j$, the agent would have to ‘simulate’ the object’s formative structure when interacting with the object. Hence in this case, the object’s formative history is being ‘simulated’ relying on the agent’s arsenal of events.
Still, the key idea is the underlying informational concept of formative object history, or structure, which is hypothesized to be the only form of object/process representation throughout the Universe.

Ironically, though quite logically, the most promising way to approach the development of structural representation seems to be to return to the single reference point we have, the original, or prehistoric, temporal form of natural numbers, and try to construct their event-based temporal generalization (Figs. 1.4, 1.5 and Chap. 3). At the same time, it is important to realize that the new form of representation must embody some previously inaccessible view of objects as evolving entities: if it does not capture a completely new to science side of reality, its purported value would be illusory. Such generalization is possible and will be preliminary outlined in Section 4. In fact, this book was motivated by the implications drawn from such structural representational formalism.

Several general remarks regarding a structural representation are in order. For historical reasons, the numeric representation, as the sole form of scientific representation, has never been seriously challenged. Obviously, this does not necessarily mean that it is superior to other possible forms of representation, since we simply have not tried any of them. Also, by far, not any choice of the representation set will be acceptable. To be adopted in science, a structural representation must, first, be universally applicable, second, be considerably superior to the numeric form in terms of the relevant information it provides about the actual objects or processes, and third, lead to a more transparent formal apparatus. Otherwise it simply will not be adopted. Naturally, when it is initially adopted, there will be a transitional period, when the two forms of representation will coexist.

So a structural representation, on the one hand, would have to capture essentially different kind of information than its predecessor about the actual processes in Nature (structural information), and on the other hand, it would, most likely, have to be a far-reaching generalization of the natural numbers.

Despite the enormous success of the numeric formalism, we should expect the new formalism to address the needs of all sciences much better than its predecessor. The candidate for such a formalism outlined in this book promises not only that but it also accounts for the nature of induction—including the nature of classes (of objects) in the Universe—the nature of time, as well as the nature of ‘emergence’. However, only time will tell what the deeper relations between the two formalisms are.

The development of the proposed structural representation was motivated by the incorporation of ‘structure’ immediately at the level of data representation, rather than seeking it ‘indirectly’, via spatial (numeric), including geometric and algebraic, mathematical structures. So the new ‘mathematics’, once developed, can be more legitimately (than the conventional one) called structural.

Again, the numeric formalism became the representational formalism during the above Scientific Revolution. Originally, used strictly for accounting purposes—e.g. seven pigs or five measures of barley—numbers are not suited for representing objects or processes, for which they are now used inside and outside of science. For example, a tree’s or a galaxy’s mass, volume, or energy, convey hardly any information about their structure, which is what object’s representation should all be about. Indeed, if a vehicle and a tree have the same mass, this provides very little information about the two objects. Besides, if in three month a mature tree grew—or in a billion years a mature galaxy evolved—their masses changed but their basic structure may not have changed substantially, and, in fact, we would be able to recognize them as the same tree or the same galaxy. This suggests that our minds’ representation of a tree or a galaxy is not numeric. To repeat: the main information to be captured in the object’s representation is the object structure, where the very concept of ‘structure’ is
supposed to be elucidated by the appropriate representational formalism. It appears that all organisms rely on the representations of that kind. So the main scientific revolution will be associated with the transition from the quantitative (numeric) to the qualitative (structural) description of Nature.

On an optimistic note, it appears that we will not need to go through many different representational formalisms, since each new one would bring us significantly closer to the structure of actual processes in Nature. In fact, if the two hypotheses about the structure of reality proposed in Section 6 will be corroborated, we may need to undergo just one such transition, since the above structural representation might essentially be a ‘mirror’ copy of the structure of actual processes in Nature!

2. The old mind-matter split is now costing us much more than we can afford

In Chapters 5 and 6, we will discuss the fateful mind-matter split which was quite opportunely postulated by the fathers of the Scientific Revolution. Indeed, the only mathematical basis available to them, the numeric framework, as I suggested above, is not suitable for modeling the combined mind-matter reality (even though such undertaking would have been unthinkable at the time).

Influenced, besides the Christian outlook, by the then dominant clockwork technology, the previously unprecedented radical mind-matter split was also motivated by the pervasive at the time view that the transcendent Mind, the Creator, not unlike a clockmaker, designed and produced all of Nature (remaining outside it). Moreover, it was assumed that since our minds originate directly from the Mind and are of non-spatial nature, they are also not part of the ‘material’ Nature, which is based on the mechanistic principles. Yet decisive for the present state of science were the following two implicit working assumptions. First, since there is nothing ‘scientific’ one could say about the mental (as ‘part’ of the divine), the scientific study of Nature can proceed, with no negative consequences, by excluding the mental, and hence informational, from it. And second, the ‘material’, i.e. spatially extended, Universe can be adequately modeled relying on the traditional mathematical—numeric and geometric—considerations. This strictly ‘material’ orientation of science—restricting it to the spatial considerations only—has now become synonymous with the scientific view of Nature.

Thus, following the Scientific Revolution, all the ‘mental’—or equivalently, all the informational—had been eliminated from the scientific picture, and, today, no vague appeals to mind in quantum mechanics and the naïve efforts by neuroscientists, psychologists, and artificial intelligence researchers can change the situation. Why? Briefly, on the one hand, the founders of modern science assumed (correctly) that the mind is of non-spatial nature. On the other hand, they have laid the foundations of our science, i.e. of physics and astronomy, around the (spatial) concept of motion understood within the numeric formalism. But, as I will argue, the proper treatment of formative, or equivalently informational, processes in Nature is not possible within this formalism.

Once again, I will argue in Chapters 6, 7 that, on the formal side, the elimination of the mental from the scientific picture has been sustained and entrenched by the intrinsic structure of the numeric formalism. The same intrinsic structure is also responsible for the implicit elimination of time in physics. So here is the main reason, not understood before, for starting our scientific journey anew (Fig. 1.2): the above elimination of the mind, and hence of the informational, cannot be reversed within the numeric framework, because, as we will see, within this framework a structural evolution of an object cannot be addressed. It appears that in order to bring the mind into a scientific view of the Universe, we need to switch to a fundamentally new, structural, form of data representation.
Although such new beginning could not have been productively embarked upon until the second half of the last century, it is now long overdue. Here are just several relevant observations made during the last century, interestingly enough, not by scientists but by the historians and philosophers of science. The first one is made in 1965 by the late prominent French historian and philosopher of science Alexandre Koyré, who coined the phrase “Scientific Revolution”:

 Yet there is something for which Newton—or better to say not Newton alone, but modern science in general—can still be made responsible: it is splitting of our world in two. … [Science substituted] for our world of quality and sense perception, the world in which we live, and love, and die, another world—the world of quantity, or reified geometry, a world in which, though there is place for everything, there is no place for man. Thus the world of science … became estranged and utterly divorced from the world of life, which science has been unable to explain—not even to explain away by calling it ‘subjective’.

 True, these worlds are everyday—and even more and more—connected by praxis. Yet for theory they are divided by an abyss.

 Two worlds: this means two truths. Or no truth at all.

 This is the tragedy of the modern mind which ‘solved the riddle of the universe,’ but only to replace it by another riddle: the riddle of itself.  

 The next, overly harsh but perceptive, observation—which will be clarified as we progress—is made in 1932 by the late American historian of science and philosopher Edwin Burtt, who is also one of three-four pioneers of the modern view of the Scientific Revolution:

 It does seem like strange perversity in these Newtonian scientists to further their own conquests of external nature by loading on mind everything refractory to exact mathematical handling and thus rendering the latter still more difficult to study scientifically than it had been before. Did it never cross their minds that sooner or later people would appear who craved verifiable knowledge about mind in the same way they craved it about physical events, and who might reasonably curse their elder scientific brethren for buying easier success in their own enterprise by throwing extra handicaps in the way of their successors . . . ? Apparently not; mind was to them a convenient receptacle for the refuse, the chips and whittlings of science, rather than a possible object of scientific knowledge.

 The third observation is made in 1986 by the contemporary American philosopher Thomas Nagel and is, of course, completely consistent with the views of the fathers of the Scientific Revolution:

 To insist on trying to explain the mind in terms of concepts and theories that have been developed exclusively to explain nonmental phenomena is, in view of the radically distinguishing characteristics of the mental, both intellectually backward and scientifically suicidal. The difference between mental and physical [as we understand it now] is far greater than the difference between electrical and mechanical. We need entirely new intellectual tools … [My italics].
And finally, here is a more recent observation by Ian Marshal and Danah Zohar regarding the social consequences of the resulting scientific view:

The mechanists’ science succeeded in undermining many of the central beliefs of traditional Western religion, but it left nothing in its place. … Today we are free from a great deal, but we have very little idea of what we are free for.

The sharp divide between the observer and observed in mechanistic science, and the accompanying picture of a physical world composed of lifeless, brute matter, places human beings and their projects outside the context of nature. Nature becomes an object, something to be observed, conquered, and used. Technology is a means to this end. Today’s ecological crisis is in large part the product of such thinking, but we have no new overall model of nature, nor of a relationship between the human and the natural, from which we might derive new thinking. [The last italics are mine] 9

I am going to argue that the cause of the above, the mind-matter split, is not an inevitable price we have to pay for doing science: as I mentioned above, we can overcome this split, and it appears that we have the opportunity to do it now rather than wait for centuries as some have been forecasting.

At the same time, it is understood that the elimination of the mind-matter split within the new formalism (new ‘mathematics’), should not be achieved at the expense of the general scientific picture. Indeed, I have reasons to expect, and we will discuss them later, that the adoption of the ‘right’ structural formalism can only benefit each and every science.

Moreover, there are also many reasons to believe that—as was the case with our current scientific paradigm—the structural paradigm should change our moral, social, and economic climates. In this case, however, the elimination of the mind-matter split can only harmonize our relationship with Nature rather than contribute to our further alienation. Starting with this chapter, I point out why numbers—introduced originally for accounting purposes but later recruited as a form of object representation—decisively contributed to the many dead-ends our society is currently facing. Although I do not focus on such issues, from the humanistic side, they might be the most important considerations in favor of the structural scientific paradigm.

In general, there is plenty of evidence that we are on the threshold of historically unprecedented transformations, both social and scientific. And although we do not know which one of those two will lead the way, taking into consideration the role of science in our economy and culture, it is quite possible that the scientific change will become the catalyst. Concerning the coming scientific revolution, the important general question is this: How radical will it be? Is it going to be conceptually, more or less, incremental, like the previous scientific transitions, or non-incremental?

Most scientists—since scientific models have replaced for them spiritual ones, with all the related emotional attachments—simply shut out the much more painful possibility of the historically unprecedented, non-incremental, change. Another important reason is that such changes would also result, to put it mildly, in the deflation of their professional education and experience.

From the above, you can intuit my answer to the same question: I believe this conceptual transition is going to be more drastic than the humankind has ever experienced since the emergence of numbers and cities. I already mentioned above a radically new, non-numeric, form of data representation and the elimination of the mind-matter split as two reasons. Some other, concomitant, reasons will be discussed in this chapter and throughout the book. My answer should not surprise you at all: to remove the mind-matter split—or equivalently, to bring mind into the main scientific picture—is an
unprecedented undertaking with enormous benefits. In the last century, there have been many leading scientists, including Schrödinger, Einstein, Heisenberg, and many philosophers, including Bergson, Whitehead, Čapek, who have anticipated this, non-incremental, answer. Here is one of the assessment of our transitional period, expressed in 1986 by the late American philosopher Ivor Leclerc:

… contemporary scientific development has thrown into question in an extremely fundamental way all our inherited philosophical [and scientific] concepts, categories, and basic presuppositions. Nothing like this has happened since Parmenides. … [Yet in view of the profundity of the Aristotelian insights …] we need … to come back to this source, … particularly in respect of the fundamental issues and problems. 10

I try to clarify Leclerc’s appraisal in this chapter and throughout the book. (I can’t help noting our present predicament: we live in the most paradoxical period of time in human history, when the gulf between our culture, including science, and the urgent tasks facing us is probably the greatest.)

Of course, for scientists, as for most of us, the fear of the unknown is overwhelming, and so, no doubt, one can always find the justifications for continuing with the millennia-tested numeric sorcery. After all, it has brought us thus far, hasn’t it? Yes, indeed, the numeric ‘train’ has brought us much farther than one could have expected by any means, and we should be thankful for that, but presently it has outlived its usefulness: the new, information, frontier beckons. And I do hope that some of us—particularly those who sense more acutely the present disharmony in science and the primitive state of information processing—are brave enough to keep our eyes wide open to the possibility or even necessity of the above radical conceptual change.

So, I suggest, we are fast approaching a qualitatively new scientific and cultural age in the history of mankind; we are poised to shift from the numeric representation—which prevents us from entering the Information Age proper—to the structural representation (and the associated structural measurement processes), which is the necessary prerequisite for the transition. The next section points to the problem whose solution seems to be the key to the elimination of the mind-matter split.

3. Original motivation for the development of the new formalism

Our new representational formalism—whose technical name is “evolving transformations systems” (ETS, used throughout the book)—was motivated by the closely related problems of induction and pattern classification, which, regrettably, have not been approached as a single problem. The next chapter is devoted to a brief history of this (single) ubiquitous problem that has confronted philosophy and science for well over two millennia. To begin with, I propose to consider the corresponding inductive process as the key to understanding the nature of biological—and hence even more general, in the Universe as a whole—information processing. Indeed, first, there are reasons to believe that, for all biological organisms, the underlying form of their information processing system is the same. And second, without any template in Nature, it is highly unlikely that the associated classification and learning system could have emerged during the biological evolution. Biological evolution can provide new ‘engineering’ solutions (such as the DNA or the eye), but it cannot bring about the basic information processing system itself: because of its holistic structure, this system cannot emerge incrementally. So, as I will argue, the most reasonable and the most stimulating assumption is that there exists just one basic, pre-biological, information processing paradigm in the Universe.

The all-pervasive problem of induction, or inductive learning, or pattern recognition, is briefly this: How do we recognize a previously unseen “cat” (or even “love”) after seeing just several cats
(or several examples of “love”)? In other words, how does a mind get from several cats—called “the training set”—to a representation of the entire class of cats? Actually, we have not moved at all toward solving or even understanding this pervasive and deceptively familiar problem. And this is despite the many centuries of quite extensive and intensive attempts by the greatest philosophers and the more recent sustained scientific and commercial efforts by tens of thousands of researchers and engineers at numerous universities and companies throughout the world. For example, you may not know that Google and Microsoft have increasing number (many dozens) of researchers working on it. You will better understand why in the next chapter and in Chapter 10. So what are the difficulties?

First of all, it makes sense that “the class of cats” is represented in our minds in some form. If it was not, we would not be able to recognize successfully previously unseen cats. Then, what is the form in which “the class of cats” exists in a mind? Is it related to some ‘intrinsic’ structure of a cat? What is the connection between a particular cat and the class of cats? If we deny the reality of either one of the two forms of a class existence—in Nature and in the mind—we would, then, have on our hands futile scientific tasks of explaining why biological species exist as classes, and also why, from the very beginning of evolution, each and every organism has survived by relying exclusively on the classification of objects in its environment, i.e. behaved as if the classes it ‘acquired’ exist in Nature.

Second, since the class of cats, i.e. the cat species, exists in Nature, do “the class of stars similar to our Sun” and “the class of hydrogen atoms” also exist? If the last two classes exist, they are much older than the class of cats. If classes exist in Nature, how is their existence ‘maintained’?

The informational concept of class of ‘similar’ objects—historically quite controversial (mainly because it was approached in a non-structural setting)—is a central one in this book. For now, I use it appealing to your intuition. So what does bind all cats into a class? I suggest, it is their common generative origin. Indeed, the reproduction of each cat is guided by the same generative (embryonic) process. As we know from developmental biology, this process is modified during the evolution of the class. The same is expected to be true for any class in Nature: no object emerges instantaneously. I propose that, informationally, the way Nature, and hence the mind, represent, for example, a cat is via the corresponding formative structure. Of course, a mind, in contrast to Nature, does not have access to all the relevant events, but the form of the mind’s representation of a cat must have come from a prebiological Nature, since, again, the basic form of representation is not subject to evolution.

Note the absolutely indispensable role of classes and induction in our culture and thought: the meaning of any word in any language—e.g. boat, mother, to love—is not intelligible outside the class connotation. Yet, I believe, the misunderstandings surrounding induction and the concept of class are related to the inherent inability of both, human languages and our numeric formalisms, to deal adequately with the formative structures, and as a result, with the concept of class. It appears that the proposed strategic role of induction in the future development of science has to do precisely with its inherent need for the historically unprecedented, non-numeric, form of data representation.

The unsuitability of human languages for this purpose is not surprising: the mind’s mechanism responsible for induction is of perceptual origin. But it is the reliance on our language as the medium that has caused the millennia old fundamental misconceptions about induction. Another source of the misconceptions is associated with the situation when the set of objects is not a class but is treated as such, i.e when the objects don’t have a common formative origin and hence no structural ‘glue’ binding them together. For example, to use induction to characterize the readers of a particular book
is meaningless, since this set is not a class: almost anyone can be such reader. One more persistent misconception about induction comes from the situation when one has been exposed to a sample from a subclass of some target class—for instance, one has seen only white swans—but assumes that the sample fairly represents the entire target class. Then you are liable to make wrong conclusions about the target class—e.g. that all swans are white—and the induction should not be blamed for that.

Notice that the reason why the basic mathematical induction does not require us to take similar precautions when applying it has to do with the fact that the class of natural numbers—over which this induction is carried out—is one of the simplest possible classes (see Chapter 3).

The inadequacy of the present mathematical attempts to approach classes (via equations) can be intuited: what do equations have to do with an object’s formative structure? But the main reason will be discussed in the next section and throughout the book: it has to do with the impossibility to accommodate the concept of formative structure within the ubiquitous in science concept of ‘space’. To repeat, it is the inaccessibility of a satisfactory concept of class within the spoken languages and within the numeric formalism that have been the main sources of misconceptions about induction.

So, as Aristotle, Bacon, Helmholtz, Poincare, and Russell, among many, have been suggesting (see the next chapter), it is wise to accept the central role of induction in information processing:

Induction raises perhaps the most difficult problem in the whole theory of knowledge. Every scientific law [and, in fact, all our knowledge] is established by its means, and yet it is difficult to see why we should believe it to be a valid logical process. . . . When mankind took to science, they tried to formulate logical principles justifying this kind of inference. . . . I will only say that they [the results] seem to me very unsuccessful. I am convinced that induction must have validity of some kind in some degree, but the problem of showing how or why it can be valid remains unsolved. Until it is solved, the rational man will doubt whether his food will nourish him, and whether the sun will rise tomorrow.  

Yet our core science, physics, grew out of entirely different questions, those addressing the motion of bodies in space (Chap. 5), which are not explicitly related to the formative processes in Nature. The latter, I will argue, cannot be properly approached in the familiar mathematical setting (e.g. numbers, variables, equations), developed with the former needs in mind. Regrettably, computer science has also not addressed such issues. Besides philosophers, induction has been of some concern to engineers, statisticians, cognitive scientists, and a few other groups. But the lack of progress with induction can mainly be explained by the fact that it has not been approached as a fundamentally new ‘natural science’ problem, with a strong informational bent, where classes of objects form an integral part of Nature. Still, the unprecedented aspect here is that to approach the problem accordingly, it seems, require us, for the first time in our history, to develop a new kind of formal language. While the numeric representations of objects and processes in our applied mathematics—and hence in physics—are point-based, it appears we are faced with the need to replace this ubiquitous form of representation (of geometric, or spatial, origin) with an appropriate, also universal, structural form (Figs. 1.5, 1.7, 1.8). So the monumental turning point, I suggest, is the need for a new, non-numeric, kind of formal scientific language, with which we have had no experience whatsoever.

4. The basic idea of the proposed structural representation

During my career as a computer science professor doing research in the area of pattern recognition, it had gradually become clear to me that to address the concept of class (of similar objects) one needs to
develop a fundamentally new representational formalism embodying the idea of *structural data representation*. Indeed, anything we see in Nature has a particular structure, and moreover, *all objects from the same class have similar structure*. But how can we capture the above concept of formative structure? Trained as a professional mathematician, initially, I was completely unprepared for the possibility that the present mathematics cannot offer any satisfactory answer to the question. Eventually (and hesitantly), I came to the conclusion that the appropriate object structure—and hence the concept of class itself—cannot be adequately approached relying on any one of the multitude of conventional mathematical structures. Why? Again, since all *representational* structures in applied mathematics are built around the numeric, point-based, or atemporal, representation of reality (which is of spatial origin), it slowly became clear to me that such structures cannot accommodate adequately the sought formative object structure, which is of *temporal* origin.

Eventually, we opted for the formalism where—as Whitehead, Russell and others have suspected—each object, or process, in Nature is viewed and represented as the temporal stream of interconnected events that participated in it’s formation (Fig. 1.5). Note that such streams may overlap.

Particle physics does strongly suggest that all elementary processes are streams of events of various ‘structure’, as can be gleaned from Figure 1.3, where more conspicuous events are junctions each transforming the pattern of flow of one or several processes. Generalizing and formalizing this intuitive picture, we arrive at the basic idea of the structural representation (ETS) proposed by us.¹³

---

*Figure 1.3:* Each line, or track, in this bubble chamber photo of the particle beam (coming in from the left) is actually composed of a sequence of *events*, most of which we can hardly see, but as is well known, they are there. http://cdsweb.cern.ch/record/842723/files/lhc-pho-1999-258.jpg
Figure 1.4: The proper representation of numbers 2 and 3 should be understood as a temporal construction involving the consecutive application of the same operation, or event, depicted as a square. (The number of processes that are coming in and out of such event is not of essence, as long as all events are identical and each new can be attached only to the last one.)

The informational, or structured, event is the basic ETS concept. This ‘unit’ of transformation captures the abstract idea of a junction that transforms, in a definite way, the flow of one or several “information processes” (Figs. 1.5, 1.6). Think of each such “process” as related to an abstraction of an object’s attribute. And think of a typical event as a blueprint, or informational specification, for its ‘physical’ counterpart that actually transforms—in the specified manner—some physical entity (Fig. 1.6). Among the innumerable examples surrounding us, here are just several, the first two of which are of particular interest to science: various events in the expansion of the Universe, in the development of an embryo, in the production of a document, or at an executive meeting.

Figure 1.5: Pictorial depiction of a small struct. Each larger shape stands for a particular type of event; four types are present. Also note three kinds of links (or ‘processes’) coming in (top) and out (bottom) of an event, where each kind is designated by a small solid shape: each link must maintain its kind throughout and may alternatively be marked by a fixed color. Think of an event as specifying a particular structural transformation of an object (Fig. 1.6), and of a struct, as, first, the blueprint for, and second, the record of the formative history of the corresponding object.
Both formal and informal motivations behind the development of ETS representation lead all the way to the concept of natural number. According to the universally accepted in mathematics axiomatics of natural numbers—via Peano axioms (Chap. 3)—a natural number is viewed as a very simple stream of identical events as shown in Fig. 1.4. Hence, the natural number models of a completely homogeneous process, i.e. not involving structurally different events. Note that it is not reasonable at all to expect such homogeneous form of representation to be capable of capturing relations among the structurally different events pervading the Universe (Figs. 1.3, 1.5). Indeed, an object’s mass, volume, or energy, for instance, convey hardly any structural information about the object. So, instead of treating the events as ‘indistinguishable’—and converting them into identical events within the corresponding measurement device—the intention is to focus on the events themselves, i.e. on their structure and their temporal relations. This is the basic idea behind the concept of struct (Fig. 1.5), which I am about to outline.

Returning to Figure 1.1, to contrast the numeric representation with a structural one and to give you the flavor of the ETS representation, Figure 1.5 shows, with minimal explanation, an example of a struct—the proposed far-reaching structural generalization of the natural number, i.e. a fundamentally new, event-based, form of data representation.

A struct is a local section of a ‘temporal stream’ of interconnected informational events. Each such event is understood to be outside any spatial context, and often are supposed to play the role of blueprints for their spatial realizations. Among such spatial realizations are the events we see (Fig. 1.3) or hear (e.g. a music segment). The last example of music perception plus the above two examples of developing embryo and expanding Universe should give us an intuitive access to the connection between a struct and its spatial manifestation. In particular, think of a performed musical segment as a spatially realized ‘musical struct’ (originally in the composer’s mind). In general, as in the latter example, the struct is both the informational blueprint for, and the record of, the structural evolution of the process/object it represents. (Note that the struct generation process is closely linked with the concept of class representation outlined in the next section). Regarding Fig. 1.5, keep in mind that a pictorial, albeit meaningful, depiction of struct is not the same thing as the abstract concept itself (defined formally in the first paper listed in \(12\)).

Since the proposed concept of event is an embodiment of a junction in the local flow of informational processes, the event’s structure is identified by the type of transformation such junction carries out when transforming the incoming into the outgoing ‘processes’ (Fig. 1.6). (In the special case when the incoming and outgoing processes coincide, the transformation can be thought of as ‘regeneration’.) For this reason, the event structure is mainly characterized by the types of the incoming and outgoing informational processes. Most importantly, according to the proposed formalism, the formative object structure—both in Nature and in the agent’s ‘mind’—is represented by the corresponding struct, which emerges (temporally) as the overall pattern of the interconnected events involved in the object’s formation, either natural (in Nature) or perceived (by the agent). Note that such a pattern cannot be captured by any numeric representation: in general, even the structure of a single event cannot be accounted for numerically.

I will use the term “instantiation” when referring to a struct’s spatial or other ‘physical’ realization based on the blueprint, or structure, provided by it. (See also Sect. 1.7; on the ‘pulsational’ nature of instantiation, see Vol. II.). Obviously, not all structs need to be spatially instantiated, e.g. many mental structs, including dreams.
The example of developing embryo illustrates a typical situation: most physical events are transformed by the later events and become masked. Such, later ‘invisible, features’ are pervasive part of reality and exemplify one of the key new aspects of the ETS representation, as compared to the conventional one. Thus, ETS representation is supposed to capture the formative rather than the apparent structure, and to this end it relies on the new representational ‘tool’, transformative events.

Since all processes in Nature are composed of events, examples of instantiated events are all around us: events in particle physics and in chemical reactions, events in the development of an embryo or in the expansion of the Universe, events in a mathematician’s mind when proving a theorem, events in a tiger’s mind and those composing its movement when it is pursuing a deer, etc. (A simple ‘visual’ example of an event is a two-car collision event: two cars approaching each other from the opposite directions and then collide. In this collision event, two links are coming in, moving cars, and two links are coming out, damaged cars.) The crucial hypothesis to keep in mind is that the struct as informational structure (or something similar to struct) is universal in Nature.

For those who are familiar with various generalizations of the real numbers—i.e. complex numbers, quaternions, and octonions—note that the struct has hardly anything to do with them: these are just multi-dimensional ‘versions’ of real numbers. The decisive difference is the incorporation of the structured events that capture, as was mentioned above, an entirely new, structural, side of objects.

So the struct is a new kind, temporal, generalization of natural numbers and it offers a non-spatially motivated concept of representation. We also have an entirely new conception of the discrete—the discrete as the structural. This conception is expected to clarify the quantum, or pulsational, nature of physical reality discovered at the beginning of the last century, including the discreteness of electric charge, photons, energy, etc. and even of the motion itself. In this connection, recall that

from the beginning of 1930s it was known that the electromagnetic . . . [and other] fields . . . cause transmutations, i.e. mutual transformations, of elementary particles. . . . [And] transmutations—the modern analogue of Aristotle’s substantive changes, the generation (γένεσις) and the annihilation (φασμα)—began to be considered as a form of motion more general than movement. In 1949–1950, Ya. Il. Frenkel [a leading Soviet physicist] suggested viewing a particle’s motion as a series of regenerations: transformations of the particle into a different particle and the subsequent reverse transformations. [My italics] 14
As to the (formal) structure of the ETS events, the readers familiar with various mathematical structures may have noted that the former has no relation to any of the latter ones, and hence quite likely it is a new kind of structure of purely informational nature. This observation, first, makes sense since no structural representations, understood via the formative structure, have so far emerged in science (under the ubiquitous spatial settings). Second, it brings up a deep issue of the relationship between the structural and spatial representations. Incidentally, the reluctantly adopted in physics probabilistic interpretation of quantum mechanics is already a clear testimony to the failure of the conventional spatial representation as the principal one.

Support for the (unrecognized) basic role of non-observable events in particle physics was also repeatedly expressed by a leading British scientist of the first half of the last century, Sir James Jeans: the wave picture of a particle, whatever else it may be, is never a point. Thus the “world-line” of a particle is strictly speaking, not a line at all . . . —the particle resolves itself into events. Most of these events are unobservable; it is only when two particles meet or come near to one another that we have an observable event which can affect our senses. We have no knowledge of the existence of the particle between times [events], so that observation only warrants us in regarding its existence as a succession of isolated events.

In philosophy, following the lead of A. N. Whitehead, Bertrand Russell—who in turn was followed by many others—devoted a considerable part of his five hundred page book *Human Knowledge: Its Scope and Limits* “to suggest the analysis of physical entities into structures of events, and even events, as I [he] shall try to show, may be regarded with advantage as having a structure” (Simon and Shuster, 1949, p. 250). Concluding his monumental *A History of Western Philosophy*, Russell also states: “Thus ‘matter’ is not part of the ultimate material of the world, but merely a convenient way of collecting events into bundles.” (Unwin Paperbacks, 1985, p.786)

Next, since the above structural representation has no previous analogues in science, to facilitate its initial intuitive grasp, two very simple illustrative examples are presented. The first one is related to the events around a head-on collision of two cars as perceived by an external observer (Table 1.1 and Figure 1.7). The second example (see Table 1.2 and Figure 1.8) is actually a part of the example from Section 2.9. In the second, intentionally chosen “geometric” (and hence, alas, somewhat artificial), example, I illustrate ETS representation for quite simple classes of 1- and 2-dimensional patterns in 3-dimensional space. All objects in these classes are composed of two kinds of constituents: line segments and triangles. To simplify the drawings for this example event links—which are mostly (qualitatively) distinct—are shown as undifferentiated. For more details, refer to Section 2.9.

Moving on, observe that a struct evolves when the appropriate new events occur (they are “attached” at the bottom of the struct). This embodies a radically different scientific view of how to approach change as compared to the numeric, or spatial, way, via the spatial “trajectory”. Also note that, sometimes, some of the incoming links in the latest event may happen to be connected to the outgoing links of some events that have occurred much earlier (if the corresponding links coming out of those earlier events were still ‘free’). This explains how a present event may reach far into the past. An archeological finding or a light reaching us from a distant galaxy are such examples.

Thus, as has been suspected by many, ETS postulates the structured event to be the basic informational and representational unit of ‘reality’. A very important point—and probably the main motivation for the development of ETS—is that this postulate should harmonize, or unify, our scientific perception of reality with our sensory perception, since both would rely on events (while, so far, science has relied on the numeric features). Indeed, the present profound disharmony (inconsistency?) was clearly stated by Erwin Schrödinger, a leading physicist of the last century:
An instantiation of the events

<table>
<thead>
<tr>
<th>Events</th>
<th>An instantiation of the events</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Event" /></td>
<td>two events, each, when instantiated, represents the movement of a particular car over some minimal distance; the incoming and outgoing links correspond to the particular car before and after that moment</td>
</tr>
<tr>
<td><img src="image" alt="Event" /></td>
<td>two-car head-on collision event: the incoming links correspond to the two cars just before the collision, while the outgoing links correspond to the two cars right after the collision</td>
</tr>
</tbody>
</table>

**Table 1.1:** Three events involved in the first example modeling a two-car head-on collision. The depicted geometrical shapes of the events have no spatial connotation.

![Diagram](image)

**Figure 1.7:** Pictorial depiction of the struct representing a qualitative, distant view of a two-car head-on collision and several moments preceding it.

… I have tried by simple examples, taken from … physics, to contrast the two general facts (a) that all scientific knowledge is [obtained] based on sense perception, and (b) that none the less the [resulting] scientific views of natural processes … lack all sensual qualities and therefore cannot account for the latter. ¹⁷ [See also the first epigraph at the beginning of the chapter]

Regarding the concrete structure of the (hypothesized) basic physical events comprising the processes currently called “elementary particles”, their discovery would be the new task before experimental physicists, the task requiring, obviously, radically new experimental approaches. As far as the main work in all sciences, including much of physics, is concerned, I propose that it should proceed in parallel with the latter experimental work, relying on the proposed event-based formalism. This is possible since the future modifications of the set of the preliminary chosen events can proceed incrementally, without changing the underlying, event-based, form of representation.
Table 1.2: Three events involved in the second example (their depicted geometrical shapes have no spatial connotation). Since the top event occurs only once, at the very beginning, focus on the other two events (labeled P1 and P2). The incoming (input) links of each of those events represent the processes acting on the previously instantiated extreme boundary points, while the outgoing (output) links represent the processes corresponding to the newly created extreme points, which, in our example, happen to include the input ones. So that when P1 or P2 is attached to any one of the above three events, the input point(s) are always ‘regenerated’ by this newly attached primitive and are “open for business” again.
The ETS formalism suggests that while the number of the most ‘elementary’ events in Nature is expected to be quite small, there exist a (bottom-up) hierarchy of representational stages, each with its own set of events (Chap. 14). The overall structure of every event still conforms to that mentioned above, but each event at the next stage stands for a compressed struct segment of particular structure from the previous representational stage. Due to this, multistage, structure of various objects, their instantiation processes exhibit the same multistage structure (except in the top-down direction).

I will be returning to the issue of why the struct offers the long-sought—for instance, in biology (to record the relevant evolutionary events)—form of data representation that explicates the concept of ‘formative object structure’. Of course, as discussed above, the same considerations apply to all, and not just to biological, ‘objects’. (Also, if you are wondering about the structural ‘geometry’, compare the richness of the transformation paths between two structs to its numeric counterpart.)

So, Figures 1.4 and 1.5 depict two different versions of $S_i$ (from Figure 1.1): the second one being a proper, i.e. temporal, generalization of the first. However, there is a critical difference. While the natural number can be, and has been, collapsed to a point on a line—completely obscuring its temporal origin—the struct cannot be reduced to numbers without loosing its structural, or relational, information, i.e. the types of the incoming and outgoing processes in an event and the event’s
interconnections. Hence, if the proposed role of events in Nature is correct, the introduction of complex numbers, matrices, etc. cannot essentially changed the situation in this respect: combining more numbers cannot substitute for the originally lost structure, i.e. that of the events, including the struct’s temporal structure. Moreover, it is not difficult to see why the proliferation, during the last two centuries, of numerically ‘inspired’ (including various algebraic) structures in mathematics also cannot substantially change the situation: there is no magical way to recover the qualitative, or nonnumeric, structural information missing right from the beginning (from the data representation).

Coming back to Figure 1.2, we can now intuit better why the introduction of struct should mark the beginning of a new, non-numeric, scientific tradition. The information recorded about an object by its struct is of a fundamentally different kind than that captured by the numeric representation, and it allows us to view the object in a completely new, formative, light. Although the last point will become clearer after a few, even simplified, examples (see Figure 1.7 and Section 2.9), it is so important that it bears reminding again and again. The event-based representation captures an entirely different, structural, side of reality: in contrast to the numeric (homogeneous) representation, events are non-numeric entities and are associated with the formative (temporal, structural) side of objects, i.e. with the way objects have come to be what they are. Note that the ETS representation of objects obviates additional (artificial) constructions needed for the numeric representation, e.g. vectors, matrices, etc.

As will be discussed in Chapter 3, the collapsed and more convenient form of a natural number, e.g. symbol ‘2’, has emerged historically simultaneously with the development of writing, and it is this convenient form, soon followed by various measurement practices, that have contributed to our non-temporal perception of numbers. Of course, today, at the onset of the information-processing age, we should no longer be guided by the same convenience considerations as we were at the onset of writing, 4–5 millennia ago. Furthermore, if this attempt to capture the essence of structural representation is in the right direction, the shift from geometric objects—“points”, “lines”, and “surfaces”—to “events” and “structs” in the description of Nature cannot be overestimated for the future of science. Indeed, if the universality of structured events in Nature is corroborated, there would not be any significant difference between the proposed (structural, or informational) scientific language and that of Nature, since the above events would be designating the actual informational events of similar structure, which cannot be said of points, lines, and surfaces! And yes, we should take seriously this, quite inspiring, possibility of the primacy of the new informational reality.

Comparing, again, Figures 1.4 and 1.5, one can see how the temporal concept of natural number—the origin of our collective scientific journey—served as a springboard for its temporal generalization, when a single event, out of which a natural number is built (Fig. 1.4), is replaced by several structurally different events. So the quantitative question “how many?” may now be replaced by various qualitative ones such as: “which kinds of events?, of structural patterns?, or of subpatterns?”.

The deep cultural implications of such change in the view of Nature can hardly be overestimated. This becomes clearer when we fully appreciate the incongruity between the object representation in science and the ‘biological’, or ‘natural’, object representation.

(Following a common technical habit, one might be tempted, in this case also, to try to encode numerically the above structural information, which completely misses the main point. The ETS representation forces us, from the very beginning, to approach “data”, and hence “reality”, in a fundamentally different way, via structured events that are expected to be faithful images of those
informational events actually existing in Nature. Put simply, there are profound, unbridgeable semantic and formal differences between numbers and structs.)

5. Induction and structural representation: What is the connection?

Here is the question and the answer on which to focus in this section. Why has not the concept of class (of similar objects) been introduced within the numeric framework? A short answer is: the only concept of class proposed so far is defined via the concept of class representation, considered next, and the latter depends critically on the formative object structure, which is not supported by the numeric forms of data representation. (Of course, this section addresses the issue informally.)

The central concept of class representation\(^\text{18}\)—without which the concept of class (of objects) has remained obscure—will be addresses in Volume II, but think of it as embodied in the class generating system. The core of this, exclusively informational, system is an algorithm for constructing, or generating, the corresponding struct for each possible class member. (Those may then, if needed, be instantiated, Fig. 1.9). That explains the adjective “generating” in the name of this system. The algorithm itself is a stepwise specification for constructing each of those structs and only them. Associated with each such step is the set of structural constraints restricting the kinds of struct segments admissible at this step in the construction. This means that any struct segment satisfying one of the constraints can be applied at this step, provided, of course, it can be attached to the part of the struct constructed so far. (Note that not any of the ‘admissible’ struct segments can be attached to a particular struct: the appropriate connecting links must match.) An important point to note is that these constraints do not preclude the ‘insertion’ of some ‘environmental’, or ‘external’, struct segments, in which case they become part of the resulting struct (Fig. 1.10). Of course, those struct segments enter as a result of temporal interaction of this class generating system with other generating systems (for the classes in the ‘environment’).

It is also important to keep in mind, first, that, together with objects themselves, the class representation is a constantly evolving informational specification: as each class member evolves, new class members emerge, or old ones expire, the class representation constantly changes to reflect this developing reality. And second, in a relatively ‘mature’ Universe, for most classes, the class representation is capable of ‘producing’ an enormous number of possible (different) class members.

To think of the class representation as the ‘DNA’ of a class is not a good metaphor (see the second postulate in the next section): the actual DNA is probably only a ‘hardware’ constituent for the instantiation of the organism. The class representation, being an informational concept, cannot be reduced to the instantiation hardware alone. Besides, DNA has a more individual connotation, i.e. it is presently associated with a particular organism rather than with the entire class (e.g. species).

There are several closer scientific metaphors. The first one is less known and less understood—coming from developmental biology (and was more popular in the first half of the last century)—is that of the morphogenetic, or organizing, field. This field is associated with the group of cells forming a particular (future) organ, e.g. an eye, hart, or forelimb, and is supposed to guide their specific developmental process, even when the group is transplanted to a different part of the embryo.\(^\text{19}\) The second, more recent, better known, and perhaps intuitively more transparent metaphor coming from theoretical physics is that of the holographic Universe. It suggests that a complete ‘information’ about any volume in the Universe—including the Universe itself—might be stored outside that volume, on
some enveloping two-dimensional ‘boundary’ (e.g. gravitational horizon). In other words, any part of the Universe can be, informationally, thought of as a ‘holographic image’ of the enveloping surface.\textsuperscript{20}

**Figure 1.9:** The role of class representation in the generation and (multi-stage) instantiation of the class objects. Each arrow should not be interpreted as coming out of a particular ‘location’ but as indicating the dependence on the entire class representation.

(cats are from http://www.turbosquid.com/3d-models/maya-cats-tabby-fur/604691?referral=Massimo-Righi)

**Figure 1.10:** Schematic depiction of a generic step in the construction of a struct from some class, where, for simplicity, events are shown as points. During such step, first, the environment (i.e. some classes in the environment whose generating processes run ‘faster’) may attach some struct segment(s) before the class generating system attaches its own struct segment that is admissible according to this step’s constraints.
The important related questions “how a class and object representations might be ‘stored’ in Nature”, “how the two-way relationship between a class and its particular member is implemented”, and in general, “how such informational constructions interact” raise entirely new, non-trivial issues. They cannot be dealt with relying on a conventional (spatial) setting and will have to be addressed in a completely novel experimental setting, since it is quite likely that such informational representation is not located in “space”, as one should expect from an informational representation. (In connection with the issues just mentioned, I can’t help suggesting that if, in a much more studied and well delineated case of gravity, we have been, and still are, waiting for the detection of the graviton—the particle which mediates the gravity force—for so many decades, we should have enough wisdom not to expect quick answers to those, much more subtle, questions dealing with the nature of information.)

I might note that quite analogous to the situation in biology—phylogeny vs. ontogeny—it is important to distinguish between, on the one hand, a ‘global’, very gradual process of object evolution, or formation, and on the other hand, the more immediate process of object generation. The former is associated with the evolution of the corresponding class of objects (generalization of phylogeny), while the latter should be viewed as a member of the currently existing class of objects (generalization of ontogeny). The similarities and the dissimilarities between them will become more apparent in Chapters 13 and 14, when different representational “stages” and “levels” for events and structs are introduced. In particular, during object evolution, new levels and stages—and hence new, higher-stage events as well as higher-level and higher-stage structs—gradually appear. At the same time, the process of struct generation relies on the present class representation and proceeds via a top-down event differentiation, from undifferentiated higher-stage events to lower-stage events, i.e. in the direction somewhat ‘opposite’ to that of the object/class evolution process.21

The proposed concept of class is defined via the concept of (generative) class representation: no class representation—no concept of class. Of course, such concept of class does not work for a numeric representation: points in a numeric space cannot be assumed to have any ‘hidden’ structure, and so classes in the space can only be delineated by “decision” surfaces, each “optimally” separating given finite (“training”) sets of points from each other (see Section 2.6, including Fig. 2.1). That is why no generative or any other reasonable concept of class is possible in a numeric setting.

Thus—according to the above concept of class—if an object’s formative information is not present in the “data” representation itself (as in the case of numeric representation), there seems to be no way of getting from the small “training set” of objects (e.g. several cats) to the class representation. I believe that the seemingly insurmountable difficulties encountered so far in addressing the problem of induction are the result of this state of affairs. To repeat, the connection between the concepts of structural representation and that of class is critical here: I suggest that if the object representation does not incorporate the object’s formative structure, a satisfactory concept of class simply cannot be, and in fact has not been, introduced for such data representation. These considerations should partly clarify my observation about the strategic role of induction in the new development of science.

Amazingly enough, the burgeoning fields of pattern recognition, machine learning, and data mining—the fields dealing with theoretical and applied issues related to induction—have proceeded with the development of both the statistical theory and the commercial software for classification (including Microsoft and Google) without the benefits of the concept of class. Hence, paradoxically, one is engaged in classification without knowing what a class is! No wonder that all developed programs are quite ‘brittle’, i.e. minor changes in the input data may produce quite unexpected results.
What is more, compared to the human experience where our entire knowledge is derived from the results of learning, the computerized classification, as it is practiced in the above fields, does not and cannot become the source of such knowledge (Sect. 2.6). This is by far the main impediment to the development of artificial intelligence. In contrast, the above concept of class, i.e. the concept of class representation, offers a rich source of information, consistent with the proposed central status of induction. This status of induction already Aristotle thought to be the only foundation on top of which the logic, introduced by him, as well as all of our knowledge is supposed to be built (Sect. 2.1).

So one of the main reasons why we settled on the above ETS formalism has to do with its intrinsic capability to accommodate, for the first time, a sensible concept of class and, as we expect, to ensure the solution of the inductive problem. The latter involves a reliable inductive ‘class recovery’: for example, the ‘recovery’ of the class of cats based on a small sample of its members. What are the reasons for expecting a successful resolution of the millennia old problem of induction?

First, the proposed representation, the struct, for the first time, carries extensive formative information about the object it represents, so that it captures fundamentally different kind of information compared to the numeric forms of representation. And second, according to the above definition of class, this information is directly relevant to the recovery of the corresponding class: all objects from the same class have ‘similar’ formative histories and each of those is explicitly recorded in the corresponding struct. For example, it is natural to expect that several ‘cat’ structs should provide adequate information for the recovery of the generative structure for the class of cats. In other words, if an agent—based on its arsenal of events—possesses the formative structures of, let’s say, 20 cats, then the agent should be able to extract the appropriate struct ‘pieces’ and the ‘rules’ for putting them together to capture the generative structure of the class of cats (see the textbox at the beginning of the section). This should be possible, if, indeed, it turns out, as proposed by the above definition of class, that all cats have similar formative structures, with a common generative origin. But everything we know from biology, especially developmental biology, and linguistics points in that direction. (Again, keep in mind that here a “cat’s struct” refers to an agent’s representation of a cat, which differs substantially from another, complete, struct representation of the same cat in Nature.)

6. Informational organization of Nature

Before outlining the proposed organization, I should draw your attention to the fact that, so far, science has not addressed this issue. In particular, science has not addressed the question of structural regularity in Nature: why all objects and processes in the Universe fall into clearly delineated classes, e.g. classes of galaxies, atoms, molecules, stones, trees. However, the known physical laws do not explain at all this structuring tendency in the Universe, which calls for new approach(es) to science.

I begin with the two main proposed hypotheses, or postulates, regarding the informational structure and organization of Nature. They are the first of this kind—i.e. explicitly addressing this informational structure—and they lie at the very foundation of the proposed structural formalism.

1. The primary (informational) structure of all processes in Nature: the underlying structure of each process is the informational, i.e. non-spatial, stream of the interconnected structured events (Fig. 1.5).
2. The underlying organization of Nature: evolving and interacting classes of informational processes form the primary organization of the Universe, where each class is specified by its class representation.

Note that the second postulate is consistent with the origin of the term ‘information’: by ‘informing’ someone we would like to ‘transmit’ the relevant ‘Forms’ (structures of the classes) in the sense of Plato and Aristotle. So the above view of Nature can be seen as a modern, informational, version of the ‘Forms’ of Plato and Aristotle. Also, it is useful to keep in mind that the most appropriate modern interpretation of the ancient Greek “eidos” (Form) is “structure”.

Both of the above hypotheses are falsifiable. The second one points to the classes as responsible for the persistence of patterns in Nature: whenever an object appears, it does so as a member of the corresponding class of objects, obeying (or sometimes) modifying the class structure, be it even the very first, initiating, member of the class. If this postulate were not true, the Universe would have been completely chaotic, hence unpredictable: every time several particular objects interact, we would not see qualitatively stable outcome and hence no regularity in Nature. Such informational explanation of the observed regularity in Nature is much more satisfactory, or less artificial, compared to the conventional, law-based, scientific picture, where the equation-based laws appear out of nowhere, i.e. they are not a natural part of the Universe. Moreover, the reality of classes and their representations would be the main reason for the prevalence of the constructive, or formative, processes in nature—in contrast to destructive, or entropic, ones (the second law of thermodynamics)—as suggested by a number of scientists and philosophers.\textsuperscript{22} I already mentioned above that such formative processes are not ‘visible’ within the conventional (numeric) formalisms.

As far as the underlying orientation of physics—and, as a consequence, of all natural sciences—is concerned, the last point (also addressed in Chap. 7 and 8) is impossible to overestimate. Indeed, our science has evolved based on the reductionist principle, which is of spatial origin: to understand the nature of things, seek their parts and assume that they are more fundamental than the wholes, since ‘obviously’ the whole is just the sum of the parts. For example, in physics, everything is reduced to the elementary particles, in chemistry, to atoms, in biology, to genes. Accordingly, physicists seek the unified theory at the point in time (the Big Bang) when the known objects of study have not yet been present. However, since the Universe consists of various structured entities at all observational levels, it is more productive to seek the key in the opposite direction, i.e. in understanding the ubiquitous formative, or structuring, laws of nature. Of course, that kind of reversal in the scientific orientation cannot be undertaken without the support of the appropriate structural representation. Note that the ‘obviousness’ of the reductionist principle stems from our spatial (rather than temporal) experience: things can ‘easily’ be decomposed and recomposed. Yet, in the informational, or temporal, realm, this principle breaks down, mainly because the flow of events cannot be reversed.

The above two informational postulates also suggest that in the beginning was neither the “Word”, as mentioned in the Bible, nor the “Deed”, as suggested by Goethe’s Dr. Faust, but was the “Event”, which was the informational blueprint for the corresponding spatial event that followed.

Again, I wish to draw your attention to the above, completely new and important, feature in the structure of the proposed formalism: in contrast to the more ‘promiscuous’ in this respect numeric formalism, it directly postulates the underlying structure of reality in the form of the two basic hypotheses. Such upfront hypotheses, on the one hand, make the formalism relatively easier to falsify,
and on the other hand, if they will stand the test of time, we will not need to speculate as much as we do now about the nature of reality. Both features are quite desirable: the explicit declaration of the basic informational structure of the Universe offers new, critical, falsifiability criterion for the proposed formalism. For example, the discovery of the process that cannot belong to any class or of an event whose structure is strongly inconsistent with the proposed one would falsify the formalism (minor inconsistencies may simply lead to a slight modification of the event structure).

In light of the above hypotheses, we should approach Nature from a fundamentally new perspective, entirely different from the one that have dominated our science until now. From this perspective, the central cognitive process of induction, instead of considered as ‘artificial’, should be viewed as the biological utilization of the basic informational infrastructure of Nature. Then, the wide chasm between the mind and matter disappears, since the mind relies on the same, class-based, informational structure as underlies the organization of ‘matter’. I do not know of any other framework in which this chasm would be handled in such a natural way (see also the middle of the next section).

In particular, it is quite telling that in order to account for the existence of life in the Universe, during the last forty years, physicists and cosmologists found it useful to suggest various completely non-physical hypotheses directly or indirectly appealing to ‘the mind’, including the so-called “anthropic cosmological principle”.23 The above informational organization of the Universe simply obviates the basic mind-matter dualism that triggered the flow of these hypotheses in the first place.

Also note that although the proposed perspective suggests the primacy of informational reality, it stretches credulity to a much lesser extent than the conventional perspective does: the Big Bang implies the instantaneous appearance of the Universe (in the form of its mass/energy) together with the numeric laws that govern it (in the form of equations).

Regrettably, computer science has been concerned only with various models of computation and has very little to say about the above or any other “natural science” view on information processing. If anything, computer science has substantially contributed to a pervasive simplistic, computational, view of information processing in the Universe in general, and in physics and biology in particular. As we will discuss in Chapter 10, the development of (theoretical) computer science, i.e. of the theory of computation, from the very beginning has been guided by the considerations coming out of formal logic24, and this situation has played a decisive role in isolating computer science from the agenda of natural sciences. No wonder that in a (futile) attempt to change this situation some leading universities are now trying to move their computer science departments to science faculties. The recent developments such as bioinformatics and cheminformatics—initiated mainly by the researchers also trained in biology and chemistry—have not (and could not have) changed the situation: the contributions of those areas to biology and chemistry are only of computational nature, which is, of course, in line with the foundational structure of the present computer science.

The area of quantum computing has not (and could not have) contributed appreciably to our view of the informational organization of the Universe, despite some of the claims to the contrary, including the naïve and misleading idea of “programming the universe”.25 This is, again, due to the focus of the new area on the computational and the engineering aspects of quantum mechanics. But quantum mechanics itself—due to the its fundamental reliance on the observer and the related unresolved very basic issue of what constitute a measurement26—would benefit immensely from the development of the relevant information processing model, since the role of the observer (i.e. of the mind), has been
increasingly coming into prominence from the very beginning of this field. And more importantly, as will be discussed in Chapter 7, quantum mechanics, which, from the very beginning, has been faced with the discreteness of the underlying phenomena, is relying on the continuous formalism, simply because our present mathematics has not offered any relevant (discrete) representation.27

Thus, the present confusion between the computational, or algorithmic, aspect of reality and the informational, or structural, side of reality is quite persistent today. This is simply because the latter side has not been perceived as more fundamental. In particular, our computers simply compute, following our instructions; they cannot and do not process any information. Even before the development of ETS formalism, working as a computer science professor, I had been amazed at the pervasive simplistic—computational and mechanistic—understanding of the nature of information processing. Of course, such tendency becomes understandable if we keep in mind that, starting from the 16th century and its clockwork technology, our periodic infatuation with the dominant technology of the day has inevitably led to its fetishism, and that includes the latest computer metaphor.

Of course, such unexpected negative consequence of the Scientific Revolution could not have been anticipated by its founding fathers: as will become clear in Chapters 4, 5, and 10, information processing has nothing in common with the ‘matter’, as it was understood by the main heroes of this revolution. The above fundamental confusion, by itself, is another telling sign of the urgent need to deal with the present split between the physical and the mental (see Section 2), which is now seriously impeding our progress in all information processing fields, and hence in all sciences.

Nevertheless, one unexpected encouraging exception should be mentioned. There is an important area of cognitive science, linguistics, whose development points in a general information processing direction I am advocating. The founding father of modern linguistics, Noam Chomsky, from the very beginning of his work in the late 1950s, has emphasized the critical importance of ‘generativity’ both in linguistics and in the organization of the mind in general. The concept of generativity in linguistics, as proposed by Chomsky, has to do with the idea, now extensively developed, that the syntax of any sentence in any language should be viewed in terms of some (abstract) “generative grammar”. Such grammar consists of a list of production, or substitution, rules, written in the form \(A \rightarrow B\), where \(A\) and \(B\) are some abstract strings of symbols. Such rule signifies that wherever string \(A\) occurs—either by itself or as a substring—one is allowed to (but does not have to) replace it by \(B\). These ‘generative’ rules, when applied successively, can be used to generate any sentence, starting from a very simple production rule. For example, suppose we have three rules: \(S \rightarrow NV\), \(N \rightarrow \text{“the man”}\), \(V \rightarrow \text{“danced”}\) (\(S\) is for the start symbol, \(N\) is for noun phrase, and \(V\) is for verb). We can now generate the sentence “the man danced” in three steps: \(S \rightarrow NV \rightarrow \text{“the man”} V \rightarrow \text{“the man danced”}\).28

Thus, the idea of grammatical generativity or generative structure, to which we will return in Chapter 11, is somewhat similar to the above idea of formative structure but with two critical differences. First, no one in linguistics or in cognitive science in general realized that, in order to be able to take the full advantage of this idea, one would need to introduce a fundamentally new concept of structural representation. After all, compared to a struct, a string is just a linear sequence of arbitrary symbols, which carries hardly any structural, or formative, information about the actual object it refers to. And second, the still underappreciated role of the generativity in Nature must be sought not so much in the language but rather in the much more basic informational structure that the development of language itself had to rely on. In any case, the true power of generativity can only be seen within the richer form of structural representation, such as ETS.
The important lesson from the development of linguistics formulated by Chomsky is this. Since there are an unlimited number of grammatically correct sentences, which therefore cannot all be memorized, there must exist the cognitive mechanism capable of, and responsible for, generating sentences immediately, as the need arises. However, to account for such essential generative skill Chomsky is led to hypothesize the genetically innate “universal (i.e. unique for all languages) grammar”. But then, for the same reason, one is inevitably led to hypothesize the existence of many other innate counterparts of such grammar for a multitude of skills we possess (see, for example, the last reference): dreaming, movement control, mathematical skills, music composition, and in general any ‘design’ skills, including those essential to the arts. Compared to that unwieldy scenario, the above much more universal, simpler, and not specific to humans or even biological organisms informational mechanism of class representation offers immense advantages. So here too the advantage of the ETS general, class-related generative mechanism becomes apparent when we think of the simplification and unity such hypothesis brings as compared to the (indefinite) multitude of the above unrelated, somehow evolutionary evolved, and genetically embedded mechanisms.

As to the topic of “consciousness” in the Universe and its relation to various classes (of objects), I do not discuss this issue in the book, simply because I don’t think we know enough yet to justify such discussion. My focus in this book is on the new scientific language that points to a new beginning for our science, and represents the (informational) rebirth of Plato’s and Aristotle’s ideas, which could not have been properly approached during the Scientific Revolution. Later on, when we understand much better the proposed view of Nature, we will be in a better position to address such topics.

I also believe that the present scientific escapades into the origin of the Universe are premature. Why? Because, as will be discussed later, our present concept of matter and the associated formal apparatus of differential equations are quite inadequate (and were not indented) to address the questions of the origin and of the ensuing formative processes in the Universe. This inadequacy manifests itself, for example, in an increasing number of the proposed non-physical principles that have proliferated physics and astronomy during the last half a century (see this section above).

Looking into the near future, one simple but important point should be made. As was the case with the numeric representation, we need to learn how to see the world through the spectacles of the proposed structural representation. This representation is a big step into the unknown, and we cannot know right now if we land exactly in the right place. We can find this out only after the representation has been extensively battle-tested in various scientific and technological applications. However, in this book, I hope to convince you that we do need fundamentally new, structural, forms of data representation that bring in the class-oriented, or generative, view of all—and not just biological—objects in Nature. As might already be apparent from the example shown in Figure 1.8, while within the conventional view objects are perceived as more immutable, possessing fixed features, under the structural view, all objects are assumed to be the results of the class-associated generative processes, which, as information processes, are hidden from the conventional (spatial) view of reality. Yet if the proposed view is on the right track, then, in the numeric setting, no—including any future—analytical machinery is capable of the miracle of recovering the information that was not present in the original numeric data in the first place.

To summarize, I propose to identify information processes in nature with the formative ones, i.e. with those ubiquitous processes that are responsible for the maintenance of all object classes, and
hence of objects themselves. As will be discussed in Chapter 10, I am not the first to suggest the basic role of classes in nature. Obviously, so far, no science has undertaken the development of this view, which, I believe, is mainly due to the lack of the appropriate form of data representation.

As to the very ambiguous concept of “information”, I recently found the following, related and useful, characterization of an information process by a Soviet philosopher:

Hence the information process can be defined as a free movement of an invariant structure in the material carriers of various natures, and the information can then be thought of as this invariant structure circulating through the communication channels.

7. The precedence of temporal representation over the spatial according to ETS

What is the present tendency in the interpretation of time by physicists? Based on the scheme originally set in motion by the Scientific Revolution, a number of physicists are now contending—no doubt to the horror and consternation of the principal heroes of this revolution—that time is actually an illusion, and we live in the timeless Universe. Such claims are not based on any fundamentally new discoveries and, from formal point of view, should not look that surprising. Indeed, accepting the primacy of the spatial forms of representation in mathematics (and hence physics), time has been treated as an extra ‘spatial’ dimension, and all basic equations of physics are insensitive to the direction of time. Nevertheless, these claims have woken up a number of contemporary physicists to the fact that, perhaps, not all is well in the kingdom of physics, and the starkness of the claims have drawn a renewed attention to the old simmering issue of time and its role in physics.

As a result, besides the well known—but, in my opinion, not sufficiently radical—quest to rehabilitate the time in science by the late Ilya Prigogine, a number of physicists have begun to realize “that we are far from having a good grasp of the concept of time”, and what is more, “that quantum theory and general relativity are both deeply wrong about the nature of time. It is not enough to combine them. There is a deeper problem, perhaps going back to the origin of physics.” And, as you might have expected, I do agree with this comment by Lee Smolin that all solutions proposed so far to address the issue of time do not aim deeply enough. And indeed, how could they?

I mentioned it above and will argue in this volume that the issue of time cannot be addressed adequately within the numeric formalism. In other words, time cannot be understood in a spatial setting, as an extra dimension or even several of them, in which case we end up, for example, with such unnatural, but presently central, concept as instantaneous state of a system. As Whitehead and others have emphasized, “there is no Nature at an instant”: any event in Nature takes some time to happen, so a truly instantaneous slice does not speak to the physical reality, and such concept could have been motivated only by the spatial interpretation of time, for which it is more meaningful.

Thus since there are no instants, conceived as simple primary entities, there is no nature at an instant. Thus all the interrelations of matters of fact must involve transition in their essence. [34, p. 146]

There is no nature apart from transition, and there is no transition apart from temporal duration. This is the reason why the notion of an in instant of time, conceived as a primary simple fact, is nonsense. [34, p. 152]

The best available in science treatment of time in special relativity theory, via Minkowski 4-dimensional space-time, is only a relatively small improvement on the classical treatment. And although this theory already contains some hints as to the ‘illegitimacy’ of the conventional concept of time, in light of ETS, it appears that time cannot at all be adjoined to space; “time” is embedded in the
stream of (informational) events, and so the numeric time, not unsimilar to money, emerges as a quite artificial entity. To get at least some intuitive feeling for that point, compare the measurement processes for time with those for space and mass. For instance, when measuring length, we repeatedly apply some chosen yardstick, while the same idea is not applicable at all for measuring time: there is not any ‘time yardstick’ simply because we cannot set aside a unit of duration in the same way it can be done for a unit of length. Instead, we have been measuring time indirectly, relying on something else, like motion, e.g. that of the Earth around its axis or around the Sun. So, together with some modern physicists, I believe that the inability to address adequately the concept of time is the most important issue which will be responsible for the reconstruction of physics on a new basis.

So what is the new idea of time that emerges from the proposed structural representation? One of, if not the most encouraging aspect of the ETS formalism is that the structural representation itself embodies the new—irreversible and structural—idea of time: time is now embedded in the representation itself, i.e. in the struct (Fig. 1.5). This confirms the view that the “flow of time” is simply a by-product of the flow of events, and—similar to the idea of space as inseparable from the bodies (or matter) in it—time now emerges as inseparable from the irreversible stream of events. In other words, time is simply ‘dissolved’ in this stream of events. Note that there is no space involved, no spatial context: we are dealing with the purely informational flow of events, and hence time is associated with this irreversible flow of ‘information’.

Thus, the illusive irreversibility becomes now a simple consequence of the fact that none of the events—e.g. those in the expansion of the Universe—can be undone.

Moreover, when all the events are identical and each is connected to the immediately following event only, we get a very simple, ‘linear’ flow of events corresponding to a natural number. Otherwise, for practically all processes in Nature, we are left with the entirely new, ‘non-linear’ or structural, idea of time. So, again, the new view of time emerges as a far-reaching generalization of the conventional, or ‘linear’, concept of time, where the latter, via the real numbers, led to the identification of time in physics with the extra dimension.

What can be said about the concept of space emerging in light of ETS? If we assume the precedence of temporal, or informational, structure over the spatial—as has also been urged by a number of philosophers (Chapter 16)—then we are left with the following scenario. All spatial structures should emerge based on the information contained in the structural representation. In particular, to instantiate the spatial ‘region’ corresponding to an appropriate struct (not all structs refer to spatial information), one needs to instantiate the struct’s events as spatial ‘subregions’, interpreting some of the links connecting the events as the adjacency information between those subregions.

Perhaps, a reminder that many composers hear their music first “in the head” before they put it down on paper, may help to concretized the above precedence of temporal representation over the spatial. In general, it appears that our auditory perception can give us a more immediate appreciation of that precedence than a much more complex visual perception, which must also deal with the spatial instantiations of the structural representations.

Interestingly enough, as will be discussed in Chapter 7, the above precedence is consistent with a number of proposals by the physicists working in quantum gravity (loop quantum gravity), who also suggest that the space might actually be generated by some more basic, discrete, structures.
However, already today, the central field of physics, quantum mechanics, provides some evidence for the primacy of non-spatial forms of representation. For example, the unexpected need to rely on a non-conventional, i.e. probabilistic, interpretation of the wavefunction is an indication of the impossibility to find its more conventional, spatial, interpretation. In addition, the famed “indeterminacy principle” may also turn out to be an indirect evidence for the non-primacy of the spatial object representation. But, the most interesting evidence might be the well documented experimentally quantum entanglement. The presently established instantaneous ‘communication’ between several initially entangled particles—indeed of the distances that later separate them—strongly suggests that the information between them cannot pass in space. Moreover, it is quite possible that this evidence also supports discussed in Section 5 (non-spatial) concept of class representation that may mediate such communication: any interaction with one of the entangled particles transforms it, which modifies its class representation, which then automatically transforms all the particles in that class (Fig. 1.11).

![Figure 1.11: Possible (non-spatial) mechanism behind the quantum entanglement. The dashed arrows and the roman numbers represent events and their temporal order: (i) generation of the class and the emission of particles (in both directions) from that class (ii) Alice is interacting with the particle and this modifies (non-spatially) the class representation, which, in turn, modifies the class members so that (iii) Bob is now dealing with the particle from the modified class.]

8. Some general points concerning ETS and the present state of science

Quite unexpectedly, the proposed framework might vindicate the evolving structural version of the Plato’s view of reality as the instantiation of (informational) Forms. In the above scenario—using the language of Plato’s ‘shadows-in-the-cave’ metaphor—the observed spatial events, considered previously as primary, now become ‘shadows’ of the informational (non-spatial) events.

One might be tempted to point out that the ETS formalism replaces one kind of dualism, the mind-matter duality, with another, spatial-temporal, kind of dualism. In some, superficial, sense, this may
seem to be true, but from a scientific point of view there is a crucial difference. First and foremost, while the proposed formalism is expected to bring the mind into the scientific picture of the Universe, the original mind-matter split, as was mentioned at the beginning of Section 2, has completely removed the mind from that picture and left it in the dark. For the Information Age, the latter makes the mind-matter duality absolutely unacceptable. And second, in the case of ETS formalism, the use of “duality” to designate the spatial-temporal relationship (if, indeed, it turns out to be true) is not quite appropriate, since here we are dealing with the universal precedence of temporal, or informational, representation over the spatial one and hence with a causal relation between them. Appealing to the popular hardware-software distinction, one might say that, according to this scenario, ‘hardware’ (the spatial) is specified by ‘software’ (the informational).

Incidentally, already in 1920, a prominent English philosopher Samuel Alexander made the following amazing observation: “Time is the mind of Space and Space [is] the body of Time.”

Another important point to keep in mind has to do with the historically ubiquitous opposition between the process and the form, in which our knowledge, supposedly, must be embodied in the ‘permanent’ (geometric shapes, equations, etc.) and not the ‘changing’. Already some Greek thinkers, including Parmenides and Plato, sought the refuge from the Heraclitian change, or process, in Nature in the permanence of Forms, including the laws expressed by mathematical equations. Yet the proposed ETS formalism suggests a natural resolution of this opposition: class representation (Form) evolves together with the representations of its objects.

On the formal side, as we discuss in Chapter 6, the present (applied) concept of space, mainly that of the vector space, does not allow one to model the concept of an expanding space, which seems to be necessary if we are to accept in some form the Big Bang theory. On the other hand, the concept of process, encapsulated by the evolving in time ETS struct, seems to capture that reality quite naturally. Also, the conventional physical concept of “state”, formally represented by a point in some (even abstract) space—in contrast to the concept of struct—does not allow us to deal with the structurally evolving side of reality. Indeed, the spatially motivated transition from one point to another in the trajectory does not and cannot capture the ubiquitous formative (or some would say even creative) side of reality. This side, for example, is clearly exhibited by the evolving biological developmental processes and by the expanding Universe itself.

So instead of inventing various ‘justifications’ for why it is getting more and more difficult to ‘understand’ the Nature, we should simply admit that the overwhelming difficulties we encountered in understanding the nature of quantum mechanics, in applying it to chemistry, biology, and neuroscience are a clear indication that we have hit the limits of our conventional scientific models. (Of course, even the fathers of the Scientific Revolution could not have expected such models to serve us that long and that well). Yet in the face of these difficulties, the reaction we actually observe today (from some physicists and cosmologists) is akin to the Ostrich Syndrome, proclaiming that it is the mathematical objects that are the only trusted reality. In other words, the response to the above difficulties is an unprecedented—and philosophically very immature—fetishism of the present mathematics, as if the prestige of mathematics has not already reached its historical peak.

Again, the widely overlooked critical point here, which will be discussed in some of the following chapters, is that all basic mathematical models physicists have relied on have intrinsic limitations restricting their domain of applicability to the structurally non-evolving environments. But, as we
have gradually learned, such environments capture reality during a relatively static stage of its development, and hence cannot address the evolving *formative* structure of real objects or processes.

I cannot help mentioning that most biologists, for example, have accepted the various ‘promissory notes’—that physicists have given us—for their face value and concentrated on molecular biology. As a result, many biologists, in turn, have issued their own promissory notes regarding the fast future pace of progress in their own field, which have duped many biotechnology investors (for which, at times, they pay dearly 41). I wrote “most biologists”, since here, as always, there are some, unfortunately neglected, exceptions, which will be discussed later in the book. Incidentally, the field that has issued, by far, the most of the unfulfilled promissory notes is Artificial Intelligence, concerned with the computer simulation and modeling of ‘intelligent’ processes. And the reasons for the lack of *real* progress in that field are similar to the above: the inability to appreciate the fundamental inadequacy of the existing formal models, which were never intended for those purposes.

Returning, again, to one of our main questions raised in Section 2 regarding the mind-matter gulf, it is not difficult to see now that the struct—as capable of carrying both kinds of information, *subjective* and *objective*—ensures the agreement of their *forms*, which leads to the removal of that gulf. In other words, the disappearance of the gulf is ensured by the fact that the result of the structural ‘measurement’ performed by an agent on an object is recorded in the same *form* as the object’s actual representation in Nature. Indeed, given some object, the ‘subjective’ struct is constructed by an agent during its interaction with the object relying on the agent’s (evolutionary) supply of events. This is the agent’s representation of the object, which is still the object’s formative history *as perceived by the agent*. And the ‘objective’ struct is maintained by Nature and encapsulates the entire process of the object’s formation, based on the complete set of events. Of course, the agent’s supply of events, because of its evolutionary origin, is in many ways ‘consistent’ with the complete set of events.

These considerations also imply that the subjective (introspective) perception of time is not as deceptive as has been insisted by physicists and philosophers, who rely on the conventional concept of time: there is no *qualitative*, or structural, difference between the subjective and objective ‘times’.

This unity of the objective and subjective forms of representation brings about the unique and also critical feature of the proposed structural formalism: *the unity of its syntax and semantics*. As we know, in any spoken language or in a scientific model, the syntax is not related to the semantics: our choice of symbols has no relation to the structure of the actual objects they signify. For example, in any language, the syntactic structure of the word “tree” has nothing to do with the semantic, or actual, structure of a tree. And in science, we have the same situation: the syntax of the equation of the Earth’s orbit has nothing to do with the semantics of this orbit itself (which, presumably, should be understood via its formative, or evolutionary, history). While in the ETS formalism, the chosen ‘symbols’, i.e. the events, are intended to be the structural copy of their real-world counterparts, so that the formalism’s syntax and semantics are ‘congruent’. Hence, as was mentioned above, this formalism promises to radically change the nature and the role of representation in science.

This brings us back to the briefly mentioned in Section 2 transitional period we are facing now in science. Again, if the two hypotheses at the beginning of Section 6—regarding all processes as instantiations of the structs and regarding the classes as the primary units in the informational organization of the Universe—are accepted as reasonable, we are faced with the scientific change of
incomparable magnitude. And of course, I do mean something much more radical than a simple declaration of “the matter myth”, as it became popular to do among physicists.\textsuperscript{42}

In particular, to remind you about what we need to move from, let me quote Einstein:

Now it is characteristic of thought in physics, as of thought in natural science generally, that it endeavors in principle to make do with ‘space-like’ concepts alone, and strives to express with their aid all relations having the form of laws.\textsuperscript{43}

As mentioned above, the origins of this, absolutely dominant, status of “space” in mathematics (and hence in science in general) goes back to the decisive role of ancient measurement practices, but its ‘official inauguration’ happened during the Scientific Revolution. Yet, even then, prophetically enough, one of the revolution’s main protagonists, Gottfried Wilhelm Leibnitz, was quite critical of its basic scientific assumption about the primacy of space and objects in it, which, as just stated by Einstein, is still fully operational. After careful analysis, Leibnitz concluded that an object, space, and an object’s motion (among others) are not primary entities but are manifestations of the underlying “plurality”, i.e. they are manifestations of “relations” among some hypothetical non-spatial and truly fundamental entities (“monads”).\textsuperscript{44} You can see the similarity with the proposed above ETS view.

Related examples of basic physical concepts that are supposed to undergo a radical change are those of a particle and of an object as material entities continuously persisting in space. They would need to be abandoned and replaced by those of spatially instantiated structs (which are of ‘pulsational’ nature). Also, there would be no need for the mystifying and very confusing wave-particle duality: an instantiated stream of events directly exhibits both particle- and wave-like properties (Fig. 1.12). Of course, such claims about the nature of elementary “particles” should be verified experimentally.

![Figure 1.12](image)

**Figure 1.12:** Left: The Huygens’ view of light as a wave: each point on a wave front acts as a new source. Right: A schematic (and more plausible) ETS version of the Huygens’ view for a single event: an instantiated sequence of the depicted consecutive events accounts for both the observed wave and particle views of light propagation.

It is quite telling that, as was documented by John Stachel\textsuperscript{45}, throughout his entire career, Einstein, the leading physicist of the last century, has been increasingly preoccupied with the possibility that
the conventional, ‘continuous’, apparatus might be completely inadequate. For example, here are Einstein’s opinions from two of his 1954 letters:

> I consider it entirely possible that physics cannot be based upon the field concept, that is on continuous structures. Then *nothing* will remain of my whole castle in the air including the theory of gravitation, but also nothing of the rest of contemporary physics.

> I must confess that I was not able to find a way to explain the atomistic character of nature. My opinion is that if the objective description through the field as an elementary concept is not possible, then one has to find a possibility to avoid the continuum (together with space and time) altogether. But I have not the slightest idea what kind of elementary concepts could be used in such theory. ([45], p. 286)

Another example of a radical change, for example, in our understanding of biological processes, is the need to give up the role of the “survival of the fittest” *as the main one* in biological evolution: this role should be transferred to the ‘internal’ evolution, i.e. to the evolving developmental processes, which are, in turn, guided by the informational processes. Although this view is already gaining some currency in biology, that science, as suggested by a biochemist Franklin Harold, has been lacking the formal tools needed for its substantive development (something like ETS structs):

> So are we all waiting, not necessarily for a recipe but for new techniques of apprehending the utterly remote past. Without such a breakthrough, we can continue to reason, speculate and argue, but we cannot know. Unless we acquire novel and powerful methods of historical inquiry, science will effectively have reached a limit. [My italics] 46

As to mathematics, we often hear the statements that “mathematics is the science of patterns”47 and that it helps us to do advanced kinds of pattern recognition. So now we have to own up to this useful view: since ETS was motivated by the needs of pattern recognition, we should be prepared to change our mathematical ‘spectacles’ in order to see a much greater variety of patterns in Nature.

Hence, in addition to discarding the above “matter myth”, the whole methodology of scientific enquiry would have to change, including the sole reliance on the (spatial) mathematics and our measurement devices. In order to understand the latter, again, it is enough to compare the two structures depicted in Figures 1.4 and 1.5, each guiding the development of the corresponding measurement devices. The design of our present measurement devices relies on a single event to register the homogeneous structures shown in Figure 1.4, i.e. the natural numbers, while the new ‘measurement devices’—not unlike the biological sensory mechanisms—should rely on several fixed types of structured events to record the corresponding structs. (Incidentally, since, formally, the latter kind is the structural generalization of the former one, their simultaneous use in no way undermines the unity of the new approach.)

In particular, instead of the old form of pattern prediction—via numeric (spatial) measurements and equations, based on the sequences of identical events—we would be able to rely on a much more general form of pattern prediction, the class representation, based on the richer variety of structured events, to predict the structure of future processes as belonging to a particular class of processes. And as always, the time will show which of the two forms of pattern prediction is more powerful.

Some modern physicists, e.g. Lee Smolin48, already expressed their preference in the general direction of the above view of physical reality:

> From this new point of view, the universe consists of a large number of events. An event may be thought of as a smallest part of the process, a smallest unit of change. ... The universe of events is a relational universe. That is all its properties are described in term of relationships between the events. [p. 53]
[The future quantum theory] will be reformulated as a theory about the flow of information among events. ... The idea of “states” will have no place in the final theory, which will be framed around the idea about the processes and the information conveyed between them and modified within them. [pp. 210–11, my italics]

Considering the above, one should not expect the unification of two quite different scientific views of the Universe—the proposed and the present—to be a simple matter. Moreover, except for a stroke of genius, it is unreasonable to insist on seeing immediately the connection between the two views before a substantial development, with applications, of the proposed formalism takes place.

Moving on to the implications outside science, in Section 2, I quoted sympathetically four quite different sources that commented on the present state of our knowledge. The fourth quotation reminds us that our “science succeeded in undermining many of the central beliefs of traditional Western religion, but it left nothing in its place”, that “we are free from a great deal, but we have very little idea what we are free for”, and more importantly, that “we have no new overall model of nature, nor of a relationship between the human and the natural, from which we might derive new thinking”.

Indeed, the reason Nature appears to be so indifferent to us is quite simple: as mentioned in Section 2, the fathers of the Scientific Revolution have already deliberately removed our minds and anything ‘mental’ (and hence informational) from the scientific picture. I repeat, the simple reason the Universe appears to be indifferent to us—or, as the Nobel laureate physicist Steven Weinberg famously puts it, “pointless” 49—is a consequence of the basic fact that in our present scientific formalism, conceptually and formally, there is no place for the mind. (Ironically, such declaration of “pointlessness” is surprising, to say the least, because it is in conflict with the received, after the first quarter of the last century, physical wisdom itself expressed in the now-famed digest of the Niels Bohr’s view by his close associate: “It is wrong to think that the task of [new] physics is to find out how Nature is. Physics concerns what we can say about Nature.” 50)

Thus, I suggest, today, our society as a whole, including scientists, is in desperate need of the new vision of the Universe, a new metaphor that can inspire us in this and future centuries. The earlier mechanistic metaphors of physics, the amazingly simplistic metaphors of present biology (“natural selection”, which Darwin borrowed from a Scottish fruit farmer 51) and computer science (“computation”, a mechanical process) have long outlived their usefulness, and could not have done it for us. In this respect also, the newly resurrected, in an informational setting, the old metaphor of classes and induction—motivated by bringing the mind into the core of our scientific picture—seems to be the right, non-trivial, metaphor that can literally reanimate and reinvigorate our vision of the Universe. The reality of classes in Nature may turn out to be just the right, informational, embodiment of our deep-seated, perhaps for a reason, prehistoric animism. However, after being conditioned by a long scientific period of simplistic metaphors, we should have enough wisdom, including some patience, to allow ourselves to reap the full benefits of the new, informational, metaphor.

We should also come to our scientific senses and soberly reevaluate periodically issued, based on wishful thinking, promissory notes by the hard core “materialists”, who insist that the present, non-informational, version of reality is basically all there is. In this connection, it is worth recalling a wise observation by the British philosopher and historian Robin Collingwood made already in the 1930s: 52

Scientifically speaking … materialism was first to last an aspiration rather than an achievement. Its God was always a miracle-working God whose mysterious ways were past our finding out. The hope was always cherished that with the advance of science we should find them out some day; so the scientific
credit of materialism was maintained by drawing very large cheques in its own favour on assets not yet at hand. Failing experimental confirmation … a statement such as this, that the brain secretes thought in exactly the same way in which the gall-bladder secretes gall, might pass as a dogma of religion, but scientifically considered was simple bluff.

At the same time, first, the scientific common sense, based on the plain respect for the phenomenon of mind, unequivocally suggests that the integration of the mental, or informational, into the scientific picture cannot be accomplished in the usual, incremental, manner, that is, without rebuilding anew our (non-informational) scientific models. Besides, the fathers of the Scientific Revolution—including Descartes, Newton, and Leibnitz—who ‘designed’ our main scientific road, could not have been that wrong when they placed the mind, as a non-spatial entity, far above that road. Second, to avoid the situation with the above promissory notes, we should expect that any new, more encompassing, model of reality must be able, immediately, to clarify, at least to some extent, what the conventional numeric models could not—the structurally evolving, some would say creative, nature of that reality. In other words, a candidate new representational formalism should account for the missing features of reality directly, via its intrinsic structure: no promissory notes not supported by this intrinsic structure. So, since we have been exposed to a single, numeric, representational formalism only, we could not have learned about such decisive role of a representational formalism, i.e. that it is the chosen form of data representation that determines the overall structure of the resulting scientific knowledge about Nature.

As far as the scientific investment in the ETS formalism is concerned, the risks are not as high as they may seem, especially compared to the benefits and considering the absence of any other ‘reasonable’—i.e. necessarily radical (as they must be)—suggestions regarding possible new fundamental directions in information processing.

One more important conceptual benefit is the resolution of the perennial philosophical doubt that “the real essence of substances is forever unknowable”. Of course, the direction science has taken after the Scientific Revolution has contributed to the strength of this claim, and although a number of physicists, for some time, have been timidly suggesting “that events and not particles constitute the true objective reality” 53, such suggestion could not have been implemented within the classical formalism (with its reliance on non-existing in Nature points, lines, and surfaces). Yet now we can, gradually, begin to replace the spatial, point-based, or numeric, representation of objects by their structural, event-based, representation.

Lastly, I draw your attention, again, to an immediate, pragmatic, argument in favor of ETS, related to the motivation for its development, which was discussed above; in addition to the fact that all biological organisms, including us, are relying on induction and classification each minute of every waking day, there are, presently, tens of thousands of people around the world—and their number is increasing quite rapidly—who work in various data processing fields and who develop or use the induction-based software in their day-to-day professional work.

Accordingly, to set the stage, it is only fitting to begin the next chapter with a brief outline of the history of that important process, of induction. But when trying to identify the main reasons for the lack of substantive progress—especially during the last century of attempts to understand this, highly non-standard and non-trivial, process—despite the massive investments in the last half a century, it is useful to keep in mind the following point briefly mentioned closer to the end of Section 2. To a considerable extent, the misfortune of our present scientific (and social/political) predicament, including the situation with induction, is related to the rapidly growing an already enormous gulf
between the declining Western culture, accompanied by the increasing pace of our busy lives, on the one hand, and the pressing need for the *long-overdue* radical rethinking of our basic scientific (also social/political) framework, on the other. Specifically, this gulf is, inevitably, accelerating the ongoing *decline in the quality of all philosophical and aesthetic considerations in science*, which, historically, have been so vital in guiding the development of science. And it is happening at the time when these considerations are *supposed* to play a much greater role in the (historically unprecedented) choices each scientist personally and society as a whole are making today, including the funding choices regarding the new scientific directions.
Notes

3. Throughout the book I use adjective “temporal” not in the conventional sense used in physics—straight line, or linear, ordering—but in the most general sense of (‘non-linear’) temporal, or ‘causal’, precedence.
4. It was the Cornell physicist N. David Mermin who coined that phrase to designate a certain dominant interpretation of (attitude in?) quantum mechanics, although now it is often attributed to Dirac or to Feynman [http://physicstoday.org/journals/doc/PHTOAD-ft/vol_57/iss_5/10_1.shtml?bypassSSO=1] [accessed 30/06/2011].

Less technical expositions are:


21. See a simplified visual illustration (produced by Reuben Peter-Paul) of the process of spatial instantiation of the struct for the “Bubble Man” example from Part III of our first paper in note 12, [http://www.cs.unb.ca/~goldfarb/Physical_Instantiation.wmv](http://www.cs.unb.ca/~goldfarb/Physical_Instantiation.wmv).


24. See my paper in Note 12.


26. John Bell, Against ‘measurement’, *Physics World*, August 1990, pp. 33–40. It appears that the inadequacy of the conventional concept of measurement is due to the inadequacy of the entire (spatially motivated) conventional numeric framework.

27. Lev Goldfarb, Nature is fundamentally discrete but our basic formalism is not, (updated) essay for the third *FQXi* essay contest “Is Reality Digital or Analog”, 2010, [http://www.cs.unb.ca/~goldfarb/FQXi_3.pdf](http://www.cs.unb.ca/~goldfarb/FQXi_3.pdf) and Lev Goldfarb, After the Transition “from It to Bit”: Is This the Science Formerly Called Physics, (updated) essay for the fifth *FQXi* essay contest “It from Bit or Bit from It?”, 2013, [http://www.cs.unb.ca/~goldfarb/FQXi_5.pdf](http://www.cs.unb.ca/~goldfarb/FQXi_5.pdf).


37. The classical description of the physical state of a system—which is a complete description of a system in terms of its physical parameters (such as position and momentum) at a particular moment in time—does not involve any probabilistic elements, i.e. it is completely deterministic.


42. See for example, a well written popular book by Paul Davies and John Gribbin, *The Matter Myth: Dramatic Discoveries That Challenge Our Understanding of Physical Reality*, Simon & Shuster, New York, 1992. Such admissions are quite understandable in light of the overwhelming evidence against the conception of matter—as it was understood by the fathers of the Scientific Revolution—provided by the modern concept of field, which now dominates the entire physics.


Useful terms

**object** – although I regularly use this term (to keep exposition less abstract), one should keep in mind that a more accurate, or appropriate, term is ‘process’: all objects are, in fact, processes

**representation set** – this term is closely related to the next one; as shown in Figure 1.1, it refers to the basic set of entities that have been chosen for *data representation*, i.e. to represent the actual objects or processes; so far, science has relied on various ‘numeric’ representation sets

**the Scientific Revolution** – the term introduced by the philosopher and historian of science Alexandre Koyré to designate an approximate period in 16th–18th centuries during which the founding ideas and practical knowledge of the modern natural sciences and medicine emerged (on the basis of the rediscovered ancient knowledge), transforming the medieval views of nature

**representational formalism** or **scientific formalism** – I may use them interchangeably; they, especially the first one, are supposed to emphasize the dependence of a scientific language on the chosen form of data representation, i.e. on the representation set (which is part of a formalism); since any conventional scientific formalism relies on some form of numeric representation set, even if more elaborate one, I often use the collective term “**the numeric formalism**” when referring to any conventional formalism

**natural and real numbers** – natural numbers: 1, 2, 3, 4, . . .; real numbers, or simply reals, contain, in addition to natural numbers, rational numbers (ratios of natural numbers), and by far its largest subset of irrational numbers (e.g. π, \(\sqrt{2}\)), which fill the ‘gaps’ between the rational numbers; surprisingly, it turns out that the sizes of the sets of natural and rational numbers are quite ‘comparable’, while natural numbers constitute an *insignificantly* small subset of reals

**discrete** – in a scientific setting, this (still ambiguous) adjective refers to a particular feature of the corresponding representation set: its set of values can be completely enumerated by integers, i.e. that its size is much smaller than that of the reals

**structural representation** or **structural formalism** – the adjective ‘structural’ is supposed to suggest that each member of the representation set is composed of several interconnected structural units; since I don’t know of any adequate structural formalism, except the one discussed in this book (see the next term), both of these terms refer, basically, to that formalism

**emergence** – in the context of the evolution of the Universe, the appearance of novel forms of ‘matter’ possessing fundamentally new properties not exhibited by the constituents out of which these forms evolved, e.g. water vs. hydrogen and oxygen

**epicycle** – a term in the Ptolemaic system, which is a geocentric astronomical model popularized in the 2nd century AD by Ptolemy (but proposed five centuries earlier); the movement of planets and the Sun is modeled as follows: each of them is moving, first, along some larger circumference around the
Earth (called deferent) and at the same time, along a smaller circumference (called epicycle) whose center is located on the larger one; by adjusting the sizes of the circumferences and adding, if necessary, still more epicycles (within epicycles) one can make the system model the actual motion of planets with almost arbitrary accuracy; Ptolemaic model is an important counterexample to the central role of predictivity in science

field – a physical concept that involves an assignment of some numeric structure for each point in space (and time)

ETS – acronym for “evolving transformations system”, which is the original name for the structural formalism discussed in this book

induction or inductive learning – although both terms refer to the process of learning the class, e.g. the class of cats, on the basis of a small set of its members (the size of which also depends on how ‘similar’ this class to other classes under the consideration), I often use the first term in a slightly more general meaning, which includes the related topics

formative, or generative, object structure – the way how an object came to be, i.e. how it was generated or, in case of an agent, how the agent ‘perceives’ its generation; also, “generative” when used with “mechanism”, “system”, etc. refers to an informational, or algorithmic, capability of the system to generate a large, if not unbounded, number of the appropriate patterns (i.e. the representation of the corresponding objects)

class – a set of objects whose formative histories are quite similar

cognitive science – interdisciplinary field that studies the mind from an informational perspective

(structured) event – a basic unit in the representation of actual processes in Nature; such unit is postulated to be a fixed kind of junction that transforms the flow of several incoming ‘processes’ into the outgoing ones; the structure of each event is associated with the kind of transformation it accomplishes; the hypothesis is that all processes in Nature are composed of these kinds of events

struct – fundamentally new form of data representation: a temporally organized stream of interconnected (through the incoming and outgoing processes) events as shown in Figure 1.5; it is not a spatial concept

instantiation – the spatial realization of an object on the basis of its informational blueprint

phylogeny vs. ontogeny – in biology, the evolutionary development of an organism’s species, vs. the embryonic and postnatal development of an individual organism

class representation – informational mechanism for generating representations of the class members; the mechanism is embodied in the class generating system, which is, basically, the algorithm for constructing representations (i.e. structs) of all members of the class and only them; the algorithm is a specification of a stepwise process for constructing these structs

theory of computation – it deals with the questions of whether and how efficiently various problems can be solved on a ‘computer’, including various abstract models of a ‘computer’

syntax – in linguistics, it is the study of the principles and rules for constructing phrases and sentences in a natural language; it is sometimes interpreted more generally as a study of the same
principles for an abstract ‘language’, e.g. programming language; “syntax” is also often refers to the ‘structure’ in contrast to the “meaning”

semantics – the study of meaning and of the relation between the chosen symbolic notation, or signifiers (e.g. words and phrases), and what it stands for, or denotata

generative grammar – abstract rules (and the associated apparatus) for generating correct phrases and sentences in a particular language

irreversibility – “impossible to reverse”; the attribute of a process which assumes, or postulates, that any future state of the process cannot be identical to any of its previous states

entangled particles – this name was coined by Schrödinger for the following phenomenon: the quantum particle that previously interacted become later instantaneously ‘aware’ of the consequent ‘adventures’ of each other; Einstein called such phenomenon “spooky action at a distance”

wavefunction – or wave function; the name of the complex-valued function ψ (x, t) which is supposed to embody a complete description of the quantum state of a particle; in contrast to the classical physical description, |ψ|^2 gives only the probability of finding the particle in a given place at a given time

indeterminacy principle – often called uncertainty principle; limits our simultaneous knowledge of certain pairs of physical characteristics of a particle, e.g. position x and momentum p

Basic points

- The basic but silent constituent of a scientific formalism is the chosen representation set: the set of entities chosen to represent, or stand for, the actual objects or processes.
- Our present science relies on the numeric formalism, which has evolved based on the numeric representation and the associated measurement processes. Its representation set includes numbers or various numeric aggregates—e.g. complex numbers, vectors, matrices, functions.
- When viewing our entire scientific enterprise, its systematically overlooked, or taken for granted, part are these ‘numeric glasses’ we must wear when engaged in it.
- Historically, the use of numbers has undergone a curious metamorphosis: from counting to measuring and then to object representation, where the latter is the main culprit.
- During the Scientific Revolution—following the (now outdated) view of objects as composed of points in space—numbers were brought into the ‘representational business’ through this formally and physically immature view of ‘matter’. And eventually, numbers have been ‘recruited’ for all kinds of ‘non-counting’ purposes, in order to measure anything we fancied, including time, energy, and even happiness.
- We need to correct this situation by replacing the numeric object representation with another, more appropriate for that purpose representation. How can we move beyond our numeric formalism?
In this book, we will discuss the foundations of a completely new kind of scientific language, structural formalism, based on structural representation, where the results of ‘measurement’ are not numbers but some structured entities. The adjective ‘structural’ is supposed to suggest that each member of the representation set is composed of several interconnected structural units.

Of course, to be adopted in science, a structural representation must, first, be universally applicable, second, be considerably superior to the numeric form in terms of the relevant information it provides about the actual objects or processes, and third, lead to a simpler and more transparent formal apparatus.

Postulated and built into our numeric framework by the fathers of the Scientific Revolution, the mind-matter split is costing us now too much in terms of both the distorted view of physical reality and the resulting moral and social consequences. And since this split cannot be eliminated within the numeric framework, we need to start our scientific journey essentially anew, in order, finally, to liberate ourselves from this unnatural split by integrating mind into the Universe.

What originally motivated the development of the new, non-numeric, representational formalism (named ETS) is the problem of induction, which has plagued both philosophy and science for over two thousand years and which appears to be germinal to the development of information processing. This problem is about the nature of the relationship between a particular object, say a cat, and the class of similar objects to which it belongs, the class of cats.

My claim is that the ‘glue’ which binds all cats into one class has to do with the cat’s intrinsic—or more explicitly, formative—structure: all cats have similar formative ‘histories’. The latter is related to the way a cat came to be what it is via some long formative process, as are all objects: no object in Nature appears instantaneously.

The persisting misunderstanding of induction is related to the inherent inability of both human languages and the numeric formalism to deal with the concept of class. It appears that the elucidation of this concept requires a structural formalism, in which the ‘point’ (of spatial origin) in the conventional mathematics is replaced by a temporal structural entity.

Within ETS formalism any object in Nature is represented by a struct, which is a temporal stream of the interconnected events that compose it. The basic informational unit of reality—the event—is a junction transforming the flow of several ‘elementary information processes’ (see Fig. 1.5). As can be seen from Figures 1.4 and 1.5, the struct is a structural generalization of the natural number, in which a single event is replaced by several structurally different events. There is no spatial context involved.

In the new formalism, the object emerges gradually as the result of the unfolding events (in its struct representation), somewhat similar to a developing embryo unfolding on the basis of its genetic information.

The reason one can expect the struct to be adequate for the needs of induction has to do with the fact that the information captured by it is directly relevant to the recovery of the corresponding class: according to the definition of class adopted in ETS, all objects from the same class have similar ‘formative’ histories and each of those is recorded explicitly in the corresponding struct.
• To address scientifically unexamined, *structuring*, or informational, side of the Universe, two postulates are proposed:

1. The *underlying* structure of each process in Nature is the informational stream of the interconnected structured events.

2. The evolving and interacting *classes* of processes form the primary informational units in the organization of the Universe, where each class is specified by *its class representation*.

• For a given class, its *class representation*—without which the very concept of class remains obscure—is an informational ‘recipe’, or algorithm, for constructing the representation of each class member and only them.

• The class representation is a *constantly evolving entity*: as each class member evolves, new class members emerge, or old ones expire, the class representation must constantly change to reflect this developing reality.

• The above second postulate is fully consistent with the *origin of the term ‘information’*: by ‘informing’ someone we would like to ‘transmit’ various ‘Forms’ (class representations) in the sense of Plato and Aristotle.

• The central cognitive process of induction, instead of accidental to the Universe, appears to be the biological utilization of the basic informational infrastructure of Nature. The wide chasm between the mind and matter simply disappears, since the mind relies on the same, class-related, informational structure that underlies the organization of ‘matter’.

• The above postulates should clarify the present confusion between the computational, or algorithmic, aspect of reality and the more fundamental— informational, or structural—side of reality.

• There is an important area of cognitive science, linguistics, whose development points in the same general information processing direction: Chomsky’s idea of grammatical generativity and generative structure is quite similar to the idea of formative structure.

• Looking into the near future, we should keep in mind that, as was the case with the numeric representation, *we need to learn how to see the world through the spectacles* of the proposed structural representation.

• The structural representation embodies a radically new—irreversible and structural—idea of time: *time is simply embedded in the representation itself*, i.e. in the struct. The illusive irreversibility becomes now a simple consequence of the fact that none of the events can be undone: the past does not disappear.

• The struct—as capable of carrying both kinds of information, *subjective* (when employed by an agent) and *objective* (when part of Nature)—ensures the agreement of their *forms* and leads to the removal of the mind-matter split.

• This unity of the objective and subjective forms of representation brings about the unique, among all languages or formalisms, feature of the proposed formal language: *the unity of its syntax and semantics*. 

48
• According to the new formalism, there are no “particles”, there are just events and the processes composed of them.

• We urgently need a new scientific metaphor that can inspire us in this century: the earlier mechanistic metaphors of physics and the simplistic metaphors of biology (“selection”) and computer science (“computation”) have long outlived their usefulness. The newly resurrected old metaphor of classes and induction appears to be exactly the right, non-trivial, informational metaphor that can reanimate and reinvigorate our vision of the Universe.
Chapter 2

A very brief history of induction: What has been missing?

Our only hope therefore lies in a true induction.

Francis Bacon

What these [Hume’s] arguments prove—and I do not think the proof can be controverted—is, that induction is an independent logical principle, incapable of being inferred either from experience or from other logical principles, and that without this principle science is impossible.

Bertrand Russell

The analytical process by ‘construction’ does not compel us to descend, but it leaves us at the same level. We can only ascend [or generalize] by mathematical induction, for from it alone can we learn something new. Without the aid of this induction … construction would be powerless to create science.

Henri Poincaré

1. Aristotle’s unsurpassed epistemological advance: The road to knowledge via induction

We begin the story of induction with its ‘official’ founder, Aristotle of Stagira (384–322 BC), one of the greatest minds of all time. Although he does refer to Socrates as the originator, it was Aristotle who first introduced the process of induction (epagôgê)—which he defined as the process of “ascending from the particular to the general”—as a fundamental one in the theory of knowledge, or epistemology. Incidentally, he also founded the latter. In this section, I very briefly outline the relevant basic ideas, and, to bring at least some critical perspective, I will be quoting one of the most known in the last century antagonists of induction (and hence of Aristotle), Karl Popper.

First, Aristotle is the founder of, and perhaps the greatest figure in logic, and hence the appropriate accolades by Popper: “Aristotelian logic is the theory of demonstrable knowledge; and Dante was right when he called Aristotle ‘the master of all who knew’. He is the founder of the proof, the apodeixis: of the apodeictic [capable of demonstration] syllogism. He is a scientist in the scientific [sic] sense and the theoretician of scientific proof and the authoritarian claims of Science.”

In the Prior Analytics, Posterior Analytics, and Topics, Aristotle outlines the foundations of his theory of epistêmê, or of demonstrable knowledge. How did he arrive at it? Let us follow Popper’s, more or less reasonable, description.

[Aristotle] being a clever man, and a good logician, he finds that his assumption that there is demonstrable knowledge involves him in an infinite regress, because this knowledge, if demonstrated, must be logically
deduced from something else, which in turn must also be demonstrated knowledge, and therefore in its turn
deduced from something else, and so on.

So he gets to the problem: how can this infinite regress be stopped? Or: what are the real original
premises, and how do we make sure of their truth? He solves this fundamental problem of knowledge by
the doctrine that the real original premises are statements of definitions. ... Definitions, on the other hand,
give to words the meaning by convention and are therefore certain (analytical, tautological). But if they are
only conventional, and therefore certain, then all epistêmê is truth by convention and therefore certain. In
other words, all epistêmê is tautological, deduced from our definitions. This conclusion Aristotle does not
want, and he therefore proposes that there exists, on the other hand, also definitions that are not
conventional ... they are the result of “seeing the essence of a thing”, and so synthetic; they are the result
of induction [epagôgê].

This seems to have been the way in which induction entered into the theory of scientific method, of
epistemology. According to Aristotle, induction is the procedure of leading the pupil (or the scholar in the
sense of the learner) to a [state] ... , from which he can see the essence of the object of his interest. The
description of this essence he then lays down by definition as one of his fundamental principles, the archai.

... [Aristotle] does believe that we somehow arrive, by its [induction’s] help and by the intuition of the
essences of things ... at statements that describe these essences, or some essential properties, and that
these statements are, as definitions, true and certain and can serve as the ultimate premises of epistêmê, of
demonstrated scientific knowledge.

These fragments by Karl Popper are taken from Chapter 1, titled “Introduction: Aristotle’s invention
of induction and the eclipse of Presocratic cosmology”, in one of his last books. In this short chapter,
Popper several times accuses Aristotle of “double thinking” and “double talk”, and that he “had a bad
intellectual conscience when he introduced his theory.” This is not the place to address these
accusations but in Aristotle’s defense, I must mention at least two points. Both Analytics were
probably a record of his courses delivered at the Aristotle’s Lyceum when he was relatively young
(close to 347 BC) and did not come out of his pen: they were compiled and edited by the students and
later lecturers. That should (partly) take care of the “double talk”. As to the “bad intellectual
conscience”, I think accusing Aristotle of it makes no sense in light of what we know of his character.

However, coming back to the “double thinking” and “double talk”, it is only fair to Aristotle to note
that even now, after well over two millennia, we have not moved an iota towards clarifying the ideas
proposed by him. To realize them properly and to clarify what “the essence of the object” is one needs
to introduce the concepts of class and class representation, mentioned in Section 1.5 (see also Figures
1.8, 1.9 and Section 2.9) and mainly addressed in Volume II. The denials of the existence of such
nontrivial but central process as induction, most prominently by Popper himself (see Section 5
below), are explained, as mentioned in the previous chapter, by the inability of both human languages
and the numeric formalisms to approach this process meaningfully and productively. One cannot
blame Aristotle for not being able to articulate the latter more than two millennia ago!

So what did Aristotle propose? In contrast to a vast majority of modern logicians—who continue to
ignore induction—being the founder of logic, he realized that propositional knowledge, i.e.
knowledge expressed in propositions, is completely divorced from the physical world and hence
needs some grounding in the actual objects and processes. Moreover, he also realized that “the
method by which even sense-perception implants the universal is inductive”3, and so we should rely
on the same “method” to ground our propositional knowledge. This proposal seems to me quite
reasonable and, given its time, quite profound.
It is interesting to note that, before I was aware of the Aristotle’s proposal, in a paper written more than twenty years ago\(^4\), I actually outlined a preliminary formal mechanism for realizing his proposal:

The [proposed] model also suggests how various propositional object … descriptions might be generated based on the outputs of the [inductive] learning processes: these descriptions represent ‘translation’ of some information encoded in the nonpropositional ‘language’ of the corresponding transformation system [the initial version of class representation] … into the chosen logical (propositional) language, whose semantics is now defined by the ‘translation’.

As was mentioned in the previous chapter, a much more improved version of that proposal is the ETS formalism discussed in this book.

There is still the issue of Aristotelian Forms\(^5\), whose modern meaning should read “structures”. They, of course, have something to do with induction and the structure of the classes (of objects), but their relative obscurity should not be held against him: he did try his best to make sense of the nature of Forms as they were conceived by Plato, but at that time it was absolutely impossible to deal constructively with the relevant concept of informational structure. Sometimes one (inaccurately) attributes Greek noun eidos (or Latin Form) to Aristotle while the Greek noun idea to Plato: Plato himself often used eidos instead of idea. Despite the differences, both thinkers shared much about that concept. However, Aristotle emphasized the unity of Form and matter: when I hold a cup, I am holding both matter and Form. He substantially advanced both of these concepts.

Thus a chick is trying to become a hen, but it is not yet a hen; there is in it nisus [impulse] towards the form of a hen, but there is also in it something in virtue of which that nisus has not yet reached its goal, and this something is what Aristotle calls matter. Matter is thus the … unrealized potentiality; and because there is no such thing as wholly unrealized potentiality, a nisus that is altogether ineffective, there is no such thing as pure or mere matter; There is always and everywhere matter in process of organizing itself, matter acquiring form. But matter completely disappears only when form is fully realized and potentiality is resolved into actuality; hence Aristotle says that … pure actuality [think of information] contains no matter. Thus, anything situated somewhere in space is material, because it might be somewhere else and still remain itself …. [My italics]\(^6\)

So, although all ancient civilizations, including Greeks, spontaneously viewed nature as an organism, what should be of particular interest to us is that Aristotle was trying to develop a general theory of matter as an ‘organism’. As we will discuss in Chapters 4 and 5, with the main emphasis of the Scientific Revolution on the spatial motion of objects, this undertaking was reversed.

One more issue is worth mentioning in passing: the unfair perception of Aristotle as a ‘poor’ scientist by the participants of the Scientific Revolution, which still lingers today, can be partly attributed to the prevalent at that time scholastic reinterpretation of Aristotle’s teachings. Again, this is not the place to deal with the issue, but it suffices to quote, for example, Darwin’s opinion expressed in the last year of his life: “Linnaeus and Cuvier have been my two gods, though in very different ways, but they were mere schoolboys to old Aristotle.”\(^7\) And as a leading modern historian of science acknowledges, Aristotle’s “powerful influence in late antiquity and his dominance from the thirteenth century through the Renaissance resulted not from intellectual subservience on the part of scholars during those periods . . . but from the overwhelming explanatory power of his philosophical and scientific system. Aristotle prevailed through persuasion, not coercion.”\(^8\)
2. Francis Bacon and a superficial acceptance of his inductive methodology

We have no historical evidence of any major developments of induction until Francis Bacon (1561–1626), who is considered to be one of the fathers of the “scientific method”. In many ways, Bacon is a very exceptional star that shines brightly even among the brightest stars of “the century of geniuses”, as the 17th century has been aptly called. His literary skills and insights into human nature suggested to some experts that he was the one who publish his literary works under the pseudonym of Shakespeare. But for us, Bacon is particularly important since he was the only one among the founders of the “scientific method” who inverted the traditional priority of deduction over induction and insisted that induction is the foundation for the development of all sciences.

Disregarding his criticism of Aristotle—which, again, can be explained in part by the prevalent at the time scholastic interpretation of Aristotle’s logic—Bacon is responsible for the modern rebirth of induction as the central epistemological process. He was a true prophet of induction, addressing it in his main philosophical work, the Novum Organum (New Organon) published in 1620, so named to rival the well-known at the time Aristotle’s Organon, the collective name for Aristotle’s works on logic.

Bacon was not a typical philosopher: he did not believe that “the concepts embedded in common speech would prove to be the ones needed in a reformed natural philosophy—indeed quite the contrary.” Thus, in contrast to almost all—even the last century’s—philosophers and logicians, he already realized that induction cannot be properly addressed relying on the common language. Bacon also realized that

in order to furnish this induction or demonstration well and duly for its work, very many things are to be provided which no mortal has yet thought of; insomuch that greater labor will have to be spent in it than has hitherto been spent on the syllogism.

In other words, he was suggesting that a much “greater labor will have to be spent” on induction “than has hitherto been spent on” logic, which, regrettably, has not really happened for the obvious reason: the development of logic has not required truly radical break with the tradition. In retrospect, one can justify the failure of the scientists and philosophers of 17th–19th centuries with respect to induction, since induction requires a fundamentally different, ‘informational’, treatment than was possible at the time, before the advent of computers. But this justification, obviously, cannot be applied to those in the second half of the last century.

We do not need to go into all the concrete proposals Bacon made regarding inductive learning—most of them are not as important today as they were at the time—except to mention that, to help delineate the class, he insisted on using both examples from the class as well as those not belonging to the class. Moreover,

he never supposed that his method could be described in detail, prior to its employment in actual investigations. The specimen given in the Novum Organum … was explicitly described as a First Vintage, or provisional interpretation (interpretatio inchoata, II. 20); a full account would have to wait until the final part of the Instauratio Magna, the Scientia Activa, which was never written, or indeed even begun.

Bacon did spent great efforts, producing many tables, addressing what we would call now the algorithmic side of inductive learning, or how to organize induction. Modern research workers in machine learning have based their inductive learning algorithms on similar considerations, but what
distinguishes Bacon from them is his much broader perspective on the role of induction in science in general.

I should point out another Bacon’s foresight, which he actually repeated twice in Novum Organum and which has appeared to many quite puzzling. Without naming induction explicitly, he mentioned that, with the development of induction, the previous need for the extraordinary insights during scientific discoveries is reduced: “the course I propose for the discovery of sciences is such as leaves but little to the acuteness and strength of wits [intellect], but places all wits and understandings nearly on a level.” 13 And indeed, in contrast to the numeric representation, under the proposed structural representation, most patterns in nature can now be discovered much easier than before, simply because they are explicitly present in the representation itself and just need to be ‘extracted’ (see the example in Section 9 below).

Again, Bacon’s main legacy to me—which, quite understandably, got lost due to the dominance of the numeric formalism in science that is incapable of adequately addressing the induction—is his insistence on the universality of induction as both theoretical and practical methodology of science. By this he meant, and I fully agree, that a formally developed induction should be employed as the main tool in the development of each and every science.

The experimental orientation of his works made Bacon, and in particular the Solomon’s House in his New Atlantis, perhaps the central influence in the establishment of the Royal Society and earned him the title of “Father of Experimental Philosophy”. Both Newton and Darwin, among other scientists, professed that in their work they followed “true Baconian method”. Interest to Bacon in the second half of the 17th century Europe was enormous: in the Netherlands, there were forty five, in Italy, fourteen, and in France, thirty three printings/editions of his works before 1700. “The Académie Royale des Sciences, founded in 1666, was created by Colbert, chief minister to Louis XIV, in what Colbert referred to as ‘the manner suggested by Verulam’ [in 1618 Bacon was made the Lord Verulam].” 14 Over a century and a half after Bacon’s death, Kant’s magnum opus, The Critique of Pure Reason, was dedicated to him. However, in the English speaking world, epistemologically most obscure last century, true to itself, did not accepted the Bacon authority, mainly because of his heavy inductive leanings. So we are left with the one-sided acceptance of his legacy.

The accusations against Bacon—because of his phrase “conquering nature” and as one of the prophets of industrial revolution accompanied by the neglect of the environment—are not fair. First, he was talking about “conquering nature” only in the context of its deeper understanding: “we cannot command nature except by obeying her”. And second, as I already mentioned in the previous chapter and will argue throughout the book, it is our inability to fully implement his proposals that resulted in the one-sided, superficially inductive, development of science, which, in turn, has brought us to the present state of affairs. A truly inductive development of science, advocated by Bacon, should bring us much closer to Nature.

As Plato and Aristotle before him, Bacon also had to deal with Forms, and, as was the case with his illustrious predecessors, his concept of Form could not have been sufficiently clear, although his inductive algorithms were much more sophisticated. In the opinion of some researchers, Bacon emphasized Form’s “material translation in terms of ‘configuration’, ‘structure’, or ‘texture’ of bodies” 15 and, in general, their constructive nature. It is quite natural to assume that the above one-sided acceptance of his legacy—more so than in the case of Plato, who did not insist on the inductive
nature of Forms—can be attributed to the impossibility of adequately addressing induction and Forms without a fundamentally new representational formalism.

The main difficulty Aristotle and Bacon—and their modern counterparts—have been faced with is the lack of understanding of precisely what it is that one needs to extract from the examples provided for inductive leaning. This is the issue of representation introduced in the previous chapter: How do we represent objects? In other words, returning to the class of cats, how do you represent a cat, and how do you use this representation to form the concept of the class of cats? Although we will discuss it briefly in Section 9 of this chapter, it should already be clear that such questions are intimately connected with the formalism one chooses for representing a cat. We will be returning to these issues throughout this chapter. But it should not come as a surprise that within a satisfactory representational formalism the introduction of the concept of class in it should not present any substantial difficulties.

As we can see, all attempts, even by the greatest minds we considered so far, to address the concept of Form—which I would interpret as that of class representation—could not have succeeded without relying on an adequate formal language, i.e. the representational formalism, and we can be sure that, to some extent, both Aristotle and Bacon realized this. Again, the main point to keep in mind is this: once a particular representational formalism is chosen, one must now live with its intrinsic capabilities (or their lack) to deal with the concept of class.

For a more detailed outline of the history of induction before Hume see the above reference 12.

3. Hume’s “Problem of Induction”

The great Scottish philosopher David Hume (1711–1776) addressed this problem in his *A Treatise of Human Nature* (1739-40) and in its later revision *An Enquiry concerning Human Understanding* (1748). His was the first prominent attempt to deal with the issues related to the justification of induction. His observations are that, on the one hand, induction is the main principle guiding our behavior as we would not be able to perform any of our daily routines without it: the (efficient) way I pick up my cup is based on my inductive experience of picking up various cups. But on the other hand, he asks, can we rationally justify our inductive behavior? Or, in other words, how do we know, for example, that the Sun will rise tomorrow as it did before?

Hume proposes that we are simply relying on the premise that the future experience will resemble the past experience. Such principle was later called the “uniformity of nature” (and if one wants to be generous, it could be seen as a very rudimentary version of the second postulate in Section 1.6). Hume’s suggestion regarding the issue of the rationality of induction is basically this: our reliance on, or belief in, induction is not completely rational since we cannot supply any convincing arguments for it, but in a pragmatic sense this belief is ‘rational’, because it would be irrational not to employ something that has performed so exceptionally well.

Most fortunately it happens, that since reason is incapable of dispelling these clouds, nature herself suffices to that purpose, and cures me of this philosophical melancholy and delirium, either by relaxing this bent of mind, or by some avocation, and lively impression of my senses, which obliterate all these chimeras. I dine, I play a game of backgammon, I converse, and am merry with my friends; and when after three or four hours’ amusement, I would return to these speculations, they appear so cold, and strained, and ridiculous, that I cannot find in my heart to enter into them any farther. 16
One can summarize Hume’s position by Whitehead’s observation: “The theory of Induction is the despair of philosophy—and yet all our activities are based upon it”\(^\text{17}\). However, besides spawning the new area of epistemology (“justification of induction”\(^\text{18}\)), amazingly, what some philosophers have concluded from Hume’s discussions, in contrast to him, is that, since we do not have any rational justification of induction, there may be no such thing as induction. Not surprisingly, the most prominent and radical doubter, Popper, appeared in the last century, and we will return to him in Section 2.5. The following humorous depiction by Bertrand Russell of Hume’s “problem of induction” testifies to its notorious status in the last century.

There is a peculiarly painful chamber inhabited solely by philosophers who have refuted Hume. These philosophers, though in Hell, have not learned wisdom. They continue to be governed by their animal propensity towards induction. But every time that they have made an induction, the next instance falsifies it. This, however, happens only during the first hundred years of their damnation. After that, they learn to expect that an induction will be falsified, and therefore it is not falsified until another century of logical torment has altered their expectation. Throughout all eternity surprise continues, but each time at a higher logical level.\(^\text{19}\)

Of course, Russell did believe that “to justify induction as such is impossible, since it can be shown to lead quite as often to falsehood as to truth.”\(^\text{20}\)

Nevertheless, if corroborated, the second postulate at the beginning of Section 1.6 plus the appropriate inductive learning procedure within the ETS formalism give a complete rational justification of induction. Indeed, if Nature is informationally organized by means of classes and the mechanism by which we learn them is universal, there is absolutely nothing surprising about our inductive capabilities. At the same time, two obvious points should be kept in mind. First, as I mentioned in Section 1.3, if a given set of examples (e.g. white swans) all belong to a subclass of some larger target class (all swans), one should not be surprised that only this subclass, rather than the larger target class, will be learned inductively. And second, the life of a class is intimately related to the lives of their members: they emerge, change, and fade away along with their members, so when relying on a particular class, we should always remember that it may change or expire, for the consequences of which we should not blame induction. Induction does not claim that the classes involved are fixed. In fact, as everything else in this Universe, a class is also a dynamic entity, at least at two levels (supported by ETS): each of its members is changing with time and the overall membership is also changing (some members expire and some new emerge). I believe these considerations should basically dispose of the ubiquitous Hume’s “problem of induction”, including its justification, considered the most difficult and unsolved epistemological problem.

### 4. Mathematics and induction: Poincaré against Hilbert and logicists

The French mathematician Henri Poincaré (1854–1912) was the greatest and most versatile theoretical and applied mathematician of his time and one of the top mathematicians in the entire history of mathematics. He was also an outstanding physicist of his time, a co-discoverser (with Einstein) of the special theory of relativity and contributor to many other fields in physics, including electromagnetism and optics. Also, “Poincaré was described—by Popper—as the greatest philosopher of science ever.”\(^\text{21}\)
At the end of his life, Poincaré was engaged in an important debate with the logicists—the growing group of mathematicians and logicians, including, at that time, Peano, Russell, and Zermelo—whose aim was to found mathematics entirely on logic, i.e. on very simple and very transparent (symbolic) principles. After Poincaré’s death, another great mathematician David Hilbert spearheaded logicism, which, however, lost steam when Kurt Gödel’s proved his famous result on the incompleteness of arithmetic in 1931. But here, we are interested in Poincaré’s important observations—in the debate with logicists—on the role of induction in mathematics, which logicists attempted to eliminate from mathematics as ‘non-transparent’ principle, particularly from the point of view of conventional logic. In fact, as you recall from Section 2.1, this was the reason why already Aristotle had to base the logic he was creating on the ‘mysterious’ process of induction, which drew so much disapproval from Karl Popper. (Incidentally, how could have Popper ‘forgiven’ Poincaré his inductive bias?) Indeed, by any measure, induction, as Russell observed later in his life (see the third epigraph at the beginning of this chapter), has nothing in common with logic, as it is presently understood.

It is clear that Poincaré—having witnessed the substantial expansion of the role of more abstract levels of actual, as opposed to potential, infinity in mathematics and the attendant need to deal with various antinomies in set theory at the end of the 19th/beginning of the 20th centuries—felt compelled to combat this process. However, let us look briefly at what he had to say about the logicists undertaking regarding the elimination of induction.

Syllogistic [i.e. logical] reasoning remains incapable of adding anything to the data that are given it; the data are reduced to axioms, and that is all we should find in the conclusions.

[Then he talks about the process of “verification” in mathematics which involves direct substitution of concrete numbers into a formula to verify it.] Verification differs from proof … because it leads to nothing. It leads to nothing because the conclusion is nothing but the premises translated into another language. A real proof, on the other hand, is fruitful, because the conclusion is in a sense more general than the premises. … There is no science but the science of the general. It may even be said that the object of the exact sciences is to dispense with these direct verifications.22

Why then is this [inductive] view imposed upon us with such an irresistible weight of evidence? It is because it is only the affirmation of the power of the mind which knows it can conceive of the indefinite repetition of the same act, when the act is once possible. The mind has a direct intuition of this [inductive] power, and experiment can only be for it an opportunity of using it, and thereby of becoming conscious of it. …

It cannot escape our notice that there is a striking analogy [of mathematical induction] with the usual process of induction. But an essential difference exists. Induction applied to the physical sciences is always uncertain, because it is based on the belief in a general order of the universe, an order which is external to us. Mathematical induction … is, on the contrary, necessarily imposed on us, because it is only the affirmation of a property of the mind itself. …

Mathematicians therefore proceed ‘by construction’, they ‘construct’ more complicated combinations. … Great importance has been rightly attached to this process of ‘construction’, and some claim to see in it the necessary and sufficient condition of the progress of the exact sciences. Necessary, no doubt, but not sufficient! … A construction only becomes interesting when it can be placed side by side with other analogous constructions for forming species of the same genus. [Recall the concept of class representation—a highlighted part at the beginning of Section 1.5.] The analytical process ‘by construction’ does not compel us to descend, but it leaves us at the same level. We can only ascend by mathematical induction, for
from it alone can we learn something new. Without the aid of this induction, which in certain respects differs from, but is as fruitful as, physical induction, construction would be powerless to create science.

… this induction is only possible if the same operation can be repeated indefinitely. That is why the theory of chess can never become a science, for the different moves of the same piece are limited and do not resemble each other. [My italics]

Finally, in the “General Conclusion” to his last completed book on philosophy of science he makes this brilliant observation.

And in proof itself logic is not all. The real mathematical reasoning is a true induction, differing in many respects from physical induction, but, like it, proceeding from the particular to the general. All the efforts that have been made to upset this order, and to reduce mathematical induction to the rules of logic, have ended in failure, [which is] but poorly disguised by the use of a language inaccessible to the uninitiated. [My italics]

As we can see, Poincaré—who also gave us still unsurpassed introspective account of the role of the subconscious in (mathematical) discovery—emphasized the pervasive and irreducible role of induction in mathematics. In particular, he suggested that the reason why the attempts by logicists to ‘dissolve’ induction should end in failure is deeply embedded in the nature of our (inductive) mind. Nevertheless, even today, Poincaré’s appeal to our mind is considered by some as a weakness in his argument, rather than its strength, as I have been suggesting: if Nature is actually organized via classes, induction is the most natural and efficient way for the mind to deal with reality.

5. The tragicomedy of induction in the last century

Why is ‘tragicomedy’ in the section title? Indeed, on the one hand, the last century—which, in many ways, was sleepwalking towards the coming radical transition in this century—has seen an increasing number of philosophical, and I would say irrational, attacks on induction. Those are a manifestation of “the ongoing decline in the quality of all philosophical and aesthetic considerations in science” mentioned in the last paragraph of the previous chapter. (Of course, the process of confirmation of the central role of induction still continues: for example, some philosophers suggest that even the subconscious aesthetic criteria associated by scientists with a particular scientific theory are of inductive origin.) On the other hand, the second half of the last century has, for the first time in history, witnessed the emergence of technologically driven enormous demand on induction. In fact, the latter demand has intensified to such an extent that, in addition to the original (engineering) field of pattern recognition dealing with induction, many ‘new’ fields dealing, essentially, with the same problem began to appear. So the tragedy of the present situation is that the badly needed basic progress is on hold because of the decline in our scientific and philosophical competence, especially as it concerns the understanding of the nature of information processing in the Universe.

Let us begin with the philosophical tragicomedy (the first half of this section). I will consider very briefly just three phenomena: rejection of induction by a leading philosopher of science Karl Popper, Carl Hempel's paradox, and Nelson Goodman’s “new riddle of induction”.

Karl Popper (1902–1994), originally Austrian, was later “widely regarded as England’s greatest philosopher of science since Bertrand Russell.” He developed a strong anti-inductivist stand starting from his first book The Logic of Scientific Discovery, initially published in German in 1934. Popper’s rise to prominence appears to be related, besides his clear writing style, to his political
philosophy, expressed in the book *Open Society and Its Enemies* (1945), which gained favor with conservative politicians after the onset of Cold War. 29 Also, Popper’s appeal is not very surprising, if we keep in mind that most of his work appeared in the second half of the last (populist) century, that it was pushed by the conservative politicians, and that his philosophy of science is about “rationality without foundations” 30, as characterized by his own admiring disciple,

Popper claimed that all scientific inferences are basically deductive, hence there is no need at all to bring in induction. He called his philosophy “critical rationalism”, which is supposed to reflect his rejection of empiricism, including the inductivist account of science. He also claimed that our knowledge is the result of our creative imagination at work to solve concrete problems, but do not look here for any explanation of how this imagination works. Popper’s main emphasis was on the hypothetical or conjectural nature of our knowledge, including our scientific theories. He suggested that “falsifiability” of a theory—i.e. the possibility to disprove, or falsify, it—is the key criterion in evaluating whether a theory is scientific or not: a theory is scientific if and only if it is falsifiable. In general, he deemphasized the conventional view of the importance of the verifiability of a scientific theory in favor of its falsifiability, for the obvious reason that a theory can never be completely, or finally, verified by scientific testing, but can only be falsified. Yet this obvious point that a successful past performance does not fully guarantee successful future performance of a theory is not of much use in the development of science. What can we do with it? Also, it does not always work: for example, we do not really have a clear falsifiability criterion for the theory of evolution. As Ernest Nagel observed, "[Popper's] conception of the role of falsification . . . is an oversimplification that is close to being a caricature of scientific procedures.” 31 But the question of induction is a completely different story. If we do throw away induction, as was suggested by Popper, then we are in deep trouble, since, in addition to what was said above, it is induction alone that allows us to extrapolate the past performance of a theory into the future. Of course, if the ETS formalism is corroborated, the question of the utility of induction becomes completely superfluous.

Moving on to Hempel’s paradox, or the “Raven paradox”, it was discovered in 1945 by Carl Hempel, a German-born philosopher of science who later immigrated to the United States. Here is the ‘paradox’. Suppose you want to check inductively whether “all ravens are black”. But instead of looking for ravens, you follow your friend’s advice, who is a logician and who suggested to you to replace the original task by the *logically equivalent* task of checking that “anything that is not black is not raven”, i.e. that there are no ravens outside the set of all black things. Thus for example, seeing a green house does help you, albeit very insignificantly, to move towards the original goal of checking if all ravens are black. But what particularly exercised philosophers is that the same observation of a green house lends equal support, for example, to the statement “all ravens are red”, which contradicts the original statement. Notwithstanding this enthusiasm, according to the view of induction proposed in this book, if the original task *has* something to do with induction, as there is, indeed, the class of ravens, the logically equivalent task *has absolutely nothing to do with induction*—since “anything that is not black” is not a class—and hence no “paradox”, end of story. To remind you, as we discussed in Sections 1.3 and 1.5, what binds the members into a class is their common formative structure, or their structural similarity, which in the case of “anything that is not black” is simply not there. So the two tasks are logically but not inductively equivalent.

Thus, if anything, this ‘paradox’ is a clear example of why present logical languages are not suited for dealing with induction, which was, probably, already realized by Aristotle when he proposed to
base logic on classes and induction (see Section 2.1). But modern philosophers are indefatigable: Hempel’s paradox “illustrate a problem where inductive logic violates intuition. It reveals the fundamental problem of induction”. 32 In fact, quite sophisticated proposals for addressing the non-existing paradox have continued unabated up to the present time, including the paper under the intriguing name *The Doomsday Argument and Hempel’s Problem.* 33

Next, we consider Nelson Goodman’s “new riddle of induction”, which is even more starkly demonstrates the inadequacy of the conventional logical languages.

In 1954 Goodman [American philosopher] published a small book entitled *Fact, Fiction and Forecast.* The word “grue” appears in Chapter III, Section 4, which is entitled “The New Riddle of Induction”.

Goodman asks us to consider emeralds [which are bright green precious stones] that have been examined before time $t$, and to suppose that all of them have been green. Thus, by time $t$, these observations [inductively] support the hypothesis that all emeralds are green and the prediction that if we happen to examine the next emerald after time $t$, it will be green as well. … Goodman introduces a new predicate [“grue”]. Something is grue … if it is examined before time $t$ and determined to be green, or it is not examined before time $t$ and it is blue [which is a disjunction (or) of two statements]. 34

So the “paradox” has to do with the following situation: before time $t$ all emeralds are both green and grue, but after time $t$ they are, obviously green only. Hence, blame it on induction. In fact, “the new riddle of induction has become a well-known topic in contemporary analytic philosophy—so well known that only a philosophical hermit wouldn’t recognize the word ‘grue’.” 35 Again, there is no ‘paradox’ here. We are dealing here with a member (grue) of a completely useless and meaningless collection of all possible logical (and hence incomplete) descriptions of the class of emeralds. For example, here is another member from that set: Something is “grered” if it is examined before time $t$ and determined to be green, or it is not examined before time $t$ and it is red. But the natural question is this: Should we even attempt such descriptions until we come to grips with the concept of class, including its precise definition, i.e. the concept of class representation (outlined in Section 1.5)? If anything, this ‘paradox’ strongly suggests that we should not, since we would be wasting our time. And when we do have a satisfactory definition of the class, we will see that we need to develop new kinds of ‘logical’ languages that will allow us to ‘read of’ more adequately the ‘content’ of the class representation. That is all I wish to say about the “new riddle of induction”.

Before leaving philosophers, I should also mention one unusual case of the anti-inductivist stand, that of the towering figure of linguistics, Noam Chomsky, whom I have already mentioned at the end of Section 1.6. The peculiarity of the situation is that, while Chomsky introduced a very important idea of generativity in cognitive science, the particular form of generativity, Post production system (which was borrowed from computer science), somehow led him to the wrong conclusion about the unreality of induction. 36 Ironically, the same computational model, which partly led Chomsky to deny induction, has motivated the development of ETS formalism. 37 I will come back to Chomsky’s argument in the last paragraph of this chapter.

While some philosophers in the last century were unsure of what to make of induction, engineers and other specialists were discovering its enormous practical, including military, utility. Thus, in the late 1950s, the mainly engineering field of pattern recognition, or patterns classification, emerged, with its numerous applications to: handwritten and printed character recognition, fingerprint classification, image and face recognition (including satellite image recognition, military target identification, missile terrain navigation), speech recognition, text and document classification, robot
navigation, computer-aided medical diagnosis, mineral discovery, forestry (e.g. classifying infested areas based on their satellite images), agriculture, and many, many other applications. The practically unlimited range of applications should not come as a surprise at all, since inductive process—as we discuss throughout the book—is our main tool for making sense of the external world.

In particular, if properly developed, induction will unrecognizably transform all search engines as we know them today: in response to your query, you should get a much more selective set of records that match you query semantically, i.e. based on its content, rather than relying just on some words or phrases in it, as it is done today. The difference is enormous. For example, when I type right now (August 3, 2011) in Google a simple query such as “the first papers in pattern recognition” without the quotes (the query with quotes does not give any results), practically none of the resulting web pages give me the relevant information. This is directly related to the following two facts. First, my query with the quotes does not result in any web pages, i.e. there are no web pages with this phrase. Second, as a consequence, the search engine then simply has to rely on the words “first”, “papers”, “pattern”, “recognition” and the phrases “the first”, “the first paper”, “pattern recognition”, which do not allow one to properly interpret the meaning of my query. So unless there are some web pages containing the exact phrases from your query and, most importantly, these phrases capture the meaning of your query sufficiently closely, the results of the query will be quite disappointing. And even in the case when there are some web pages satisfying that condition, your query will be missing all the web pages that do not satisfy it but semantically quite relevant to it.

I draw your attention to the amazing fact that this is the best that computer science can offer after fifty years of developing various search techniques. Why has the progress in this direction been so negligent? The answer is quite obvious: as will be discussed in Chapter 10, computer science has never dealt with the general issue of semantics, which, I believe, can be properly addressed only in the above context of classes and classification. After all, semantics must be of perceptual origin (there are no other reasonable alternatives), which implies that the meaning of a phrase or a sentence can only emerge as associated with a particular abstract class that captures the “meaning” of all other, semantically equivalent, phrases. This idea, although in a somewhat more muddled form, has also been guiding the development of cognitive linguistics, a relatively new area of linguistics. We will come back to these issues in Chapter 19. Of course, I do expect that relying on the ETS formalism one would be able to specify any query, semantically, much more accurately than relying directly on its much more ambiguous (ordinary) language formulation.

Returning to the applications of induction, to get a piece of the large applied ‘inductive pie’, in the second half of the 1980s and early 1990s, at first in the USA and then around the world, two ‘new’ fields, coming from completely different directions—but addressing the same problem of induction—accomplished a successful coup. They were machine learning, coming from the direction of artificial intelligence (in computer science) and connectionism (later called artificial neural networks), coming from the direction of psychology and the emerging at that time cognitive science. How a successful (applied) scientific coup is typically accomplished in the USA in the last 30–40 years? The main path is for a researcher—or better a group of several researchers, preferably from several universities or research labs—to convince at least one administrator in at least one federal agency to begin to fund the new proposal for several years, during which the group tries to attract new people, often via their own graduate students, and publish as many papers as possible. This is exactly what happened in both cases, initially more spectacularly in the case of connectionism. Later on, many new groups of
researchers also got a piece of the same (inductive) pie, including genetic programming, inductive logic programming, reinforcement learning, and graphical models, which should tell you something about the size of the pie.

Although this will draw the wrath of many researchers in these areas, I must admit that, regrettably, despite the multitude of the above areas (or partly because of this fragmentation), no fundamentally new general scientific ideas regarding the nature of induction were discovered or even proposed. One, almost forgotten, exception is the syntactic pattern recognition, where there is still a small group of researchers working under the name of “grammatical inference”. This direction was inspired by Chomsky’s generative grammars mentioned at the end of Section 1.6.

The connectionists, for example, originally emphasized the architectural side of the brain—“parallel distributing processing” —while machine learning researchers originally emphasized formal logic and the computational side. As a result of all these activities, one field of pattern recognition, instead of focusing its efforts, has unnecessarily fragmented into many areas, providing employment to many more people coming from a great variety of backgrounds, including physicists. Now, looking back at the ferment and taking into consideration the massive human and material resources that were brought in, we still have very little to show for it in terms of our basic understanding of induction, and of course, without such basic insight no major applied breakthroughs are possible. What are the reasons for this lack of basic progress?

As I discussed in Section 1.3, induction is more abstract, does not fit into any of the earlier scientific undertakings, and what is more, we have had absolutely no formal tools with which to approach it—the situation unprecedented in the history of science. In that section, I advocated approaching induction as a fundamentally new natural science problem but with an informational bent, or in other words, to view this problem as addressing the ‘physical’ reality but in a fundamentally new way. This implies, in particular, that the overall architecture of the brain and our logical languages have nothing to do with induction, as they are incidental artifacts of biological evolution and human history. More importantly, since induction is about real classes and classification, the key question that should be answered—and which has reverberated throughout the entire history of Western philosophy—is this: What is a class of objects? None of the many areas currently dealing with induction, including the above areas, have seriously addressed this central relevant question. As has been expected by some scientists and philosophers (see the first epigraph to the previous chapter), it appears that the answer to this question cannot come relatively ‘painlessly’, as has been previously the case in science, but will probably require us to change radically our basic scientific language. Again, this should not come as a surprise at all, but on the contrary, given the nature and the scope of this scientific problem, we should be expecting it: in fact, anything less should be a suspect.

In this connection, it is also instructive to recall how the present leaders of the field, Vladimir Vapnik and (now late) Alexei Chervonenkis saw the situation in 1974:

It is interesting to note that a meaningful formulation of the pattern recognition problem appeared in 1957–58, and a formal formulation only in 1962–66. These five-to-eight years between a meaningful and a formal formulation were extremely bright years, the years of the ‘pattern recognition romantics’. In those days, it appeared that the pattern recognition problem carried within itself the beginning of some new idea, which is in no way based on the system of old concepts, one wanted to find new formulations, and not to reduce the problem to the already known mathematical schemes. In this sense, the reduction of the pattern
recognition problem to [a problem of applied statistics] … rouses some disappointment. Indeed, there are attempts to understand the problem in a more complex setting. But such attempts are extremely rare.\textsuperscript{41}

In order to construct the theory, above all, a formal scheme must be found into which the problem of pattern recognition can be embedded. This is what turned out to be difficult to accomplish. …

In essence, different points of view on the formulation of the pattern recognition problem are determined by an answer to the question: Are there any common principles adequate for describing pattern classes of various nature or the development of the corresponding [pattern] description language is a problem for the specialists in each concrete field?

If the answer is yes, then the discovery of these principles must form the main research direction in pattern recognition. It would be the main direction, since it would be general and principally new. If the answer is no, then the pattern recognition problem … can be considered to be one of the directions in applied statistics.

We still don’t have an answer to the above question and that is why the choice of the problem formulation has been, so far, a question of faith. The majority of researchers, however, have adopted the second point of view, and the theory of pattern recognition is now understood … [to be a particular direction in applied statistics].\textsuperscript{42}

In this quotation, note the initial—and quite appropriate—very high expectations regarding the fundamentally new scientific ideas that should come out of the research on the problem, as well as the acknowledgement of the unresolved search for the “common principles adequate for describing pattern classes of various nature”, i.e. the search for the universal formalism for pattern recognition. However, despite the fact that today, after thirty five years, the number of researchers working in this general area around the world must have increased at least tenfold, the situation described by Vapnik and Chervonenkis in 1974 has not fundamentally changed.

6. The unreasonable expectations of probability theory

In this section, addressed mainly to students and scientists, I briefly consider the role of probability (and statistics) in induction. In short, in case of induction, as implicitly hinted above by Vapnik and Chervonenkis—and as has often been the case in science in general—when an adequate model of the phenomenon is not known or is not necessary, probabilistic considerations take over. I consider the case of continuous probability, as it by far dominates the applications, and for our purpose, it really does not make much difference which of the two cases (discrete or continuous) is considered.

I suggested in the previous chapter that the key to unlocking the secrets of induction is a fundamentally new, structural and considerably richer, form of data representation. In other words, the numeric forms of data representation simply do not contain enough information about the actual objects to decide their class identity. So the most important, both technical and non-technical, point to keep in mind is that no analytical machinery, existing or new, developed for the numeric (data) spaces can recover the missing information, simply because, from the very beginning, that information is inaccessible in those spaces. But since the discussion of the limitations of conventional mathematical spaces is postponed to Chapter 6, here I approach this topic in a limited way.

Thus, ironically, probability theory—although also unsuitable, for the above reason, to address the central concept of class—is recruited to delineate, in a numeric space, the so-called “decision boundaries” for the classes involved (see Fig. 2.1); in particular, if a new data point falls on the appropriate side of the decision boundary, this point is classified as belonging to the class ‘assigned’
to that part of the vector space. Note that such classification is being undertaken without the benefit of the concept of class. It is instructive to consider the case of a single class. In this case one, obviously, cannot produce reliable boundary simply because we do not know where it should be: there are no members of other classes to tell us were it might be (although one can try to use a highly unreliable hypothetical probability distribution for the class to produce the decision boundary). Hence, the case of a single class merely exposes the general situation more clearly. Most significantly, if the learned classes are, indeed, the source of all knowledge—as has been suggested by many great scientists (e.g. Helmholtz, see the next section)—how can one believe that the above “decision boundaries” convey any substantive information about a class or its members? Of course, the reason such evident misconception has not been questioned is the unqualified acceptance of the numeric representation as the only one possible. Yet, according to the proposed above generative view of classes, the ‘glue’ that binds class members together has to do with their formative (non-numeric) structure. But, within the numeric representation, one simply must live with all its inherent limitations, and so the decision boundaries are the only tool to deal with the classification problem. Here, again, we have the main reason why, after such extensive and intensive scientific and commercial (multibillion) efforts, no reasonable concept of class has emerged.

**Figure 2.1:** The input data is not shown, but each real object is represented by a point in the horizontal plane (HP), while the probability of the object is associated with the vertical axis. Two classes are considered, and each of the two shown probability functions (intersecting surfaces of different shades) is associated with the corresponding class. Each function assigns a particular number on the vertical axis, “probability”, to a particular point in HP: the higher that number the more typical the class member represented by the corresponding point on HP is in that particular class. So the same point in HP, typically, has different probabilities with respect to each class. The “decision boundary” line is supposed to separate the two classes.

(The figure is a modified version from http://stats.stackexchange.com/questions/4949/calculating-the-error-of-bayes-classifier-analytically)
So, apparently, the probability theory cannot help us approach the concept of class, which would not matter much if the classes were just figments of our imagination, as many still (conveniently) believe. Again, probability theory is not a magical tool that can recover the information completely missing from the original data representation. By ignoring the concept of class, that theory has actually obscured the situation by covering up our ignorance of this basic concept. Regrettably, such obscuring role of probability theory has not been sufficiently recognized; the same situation occurred with some other phenomena, for example, quantum phenomena. Perhaps, in the case of induction, the inadequacies are, to some extent, more transparent. Unfortunately, it is the increasing work pace during the last and present centuries that habitually forces us into the stop-gap probabilistic solutions. Certainly, as a provisional and pragmatic solution, probabilistic treatment can sometimes be accepted, but what surprises me most is how entrenched such stop-gap solutions become in our super-busy age.

In light of these remarks on the basic inadequacy of the numeric representation, the above brief discussion—of the most popular among applied probabilistic treatments of induction—might suffice as representative. To those treatments one can also add such topics as Carnap's inductive logic and confirmation theory, Reichenbach's frequentism, subjectivism and Bayesian induction, etc.

It might be of interest to mention that “Karl Popper argued that probability theory alone cannot account for induction [and that in his own words] ‘the calculus of probability reveals that probabilistic support cannot be inductive support’”. But even several decades before Popper, in 1950, in the preface to Richard von Mises’s book *Probability, Statistics, and Truth* we find:

> The stated purpose of these investigations is to create a theory of induction or ‘inductive logic’. According to the basic viewpoint of this book, the theory of probability in its application to reality is itself an inductive science; its results and formulas cannot serve to found the inductive process as such, much less to provide numerical values for the plausibility of any other branch of inductive science.

The following observation made by a leading 20th century mathematician Andrey Kolmogorov—who is responsible for the modern mathematical foundations of probability theory—regarding the primacy of informational considerations over the probabilistic is even of greater interest:

> The preceding brief exposition should justify two general theses:
> 1) the basic concepts of information theory should and can be developed without the recourse to the probability theory …
> 2) introduced in this manner concepts of information theory can lay the foundations for a new concept of random, corresponding to the natural idea that random is the absence of regularity.

7. Helmholtz’s insight and the lack of progress with classes in today’s psychology

Besides Henri Poincaré, there was another towering figure of science in the second half of the 19th century and even a greater polymath, German physician and physicist Hermann von Helmholtz (1821–1894). He made outstanding contributions to physiology and psychology, theories of vision and visual perception, color vision, sensation of tone, perception of sound, geometry, law of energy conservation, electrodynamics, chemical thermodynamics, and mechanical foundation of thermodynamics. Since he is probably the greatest psychologist, his views on induction are even more valuable than Poincaré’s, although, quite tellingly, their views on induction are in complete agreement. Here are his thoughts on the role of induction expressed in his last published paper.

The final results of the experience and reflections just presented may, I believe, be summarized as follows:
1. In human beings we find reflex movements and instincts as effects of image organizations. Instincts act in the interest of the pleasure of some impressions and in avoidance of the discomfort of others.

2. Inductive inferences, executed by the unconscious activity of memory, play a commanding part in the formations of intuitions.

3. It may be doubted that there is any indication whatsoever of any other source or origin for the ideas possessed by a mature individual. [My italics] 47

Such were the conclusions of a great psychologist who was also a great natural scientist. Incidentally, although a good basic science education appears to be of crucial importance to a today’s psychologist, in reality, it is quite rare, which, I believe, partly explains the lack of progress with “concepts”—the name for classes in psychology—discussed next.

Helmholtz’s general conclusions regarding the role of induction in psychology were practically ignored, no doubt due to the more abstract nature of induction. With the emergence of cognitive science in the late 1950s–1960s, the relevant notions of concept (mental representation of a class) and category (the elements of a class) have begun to gain some attention, especially starting from the 1980s. However, again, due to the lack of an adequate formalism, the fundamental progress has been insignificant, especially given the large number of researchers involved.

Four main theories of lexical, or ‘word-sized’, concepts have been proposed. But “in one way or another, all theories regarding the structure of concepts are developments of, or reactions to, the [original] classical theory of concepts”. 48 The classical theory views concepts as composed of simpler, ‘necessary and sufficient’, concepts: to be a BACHELOR is to be MAN and UNMARRIED. The prototype theory—which originated in the 1970s in the work of Eleanor Rosch and co-workers—has a ‘probabilistic’ flavor and states that an object falls under a concept $C$ if it possesses a sufficient number of features possessed by the members of $C$: apple is a more typical FRUIT than plum, because apples share more features of fruits. The next theory of concepts—the theory of concepts—is the view that concepts stand in relation to one another in the same way as the terms of a scientific theory and that categorization is a process that strongly resembles scientific theorizing”. The fourth theory of concepts is called conceptual atomism. “A radical alternative to all of the theories we’ve mentioned … is conceptual atomism, the view that lexical concepts have no semantic structure. According to conceptual atomism, the content of a concept isn't determined by its relation to other concepts but by its relation to the world.” 49

As has been the case in philosophy, in cognitive science, there are also the deniers of induction. The latest one is Edouard Machery, whose book Doing Without Concepts was recently published.

So, the

[research into the nature of concepts is ongoing, in both philosophy and psychology, and there is no general consensus in either field as to the preferred theory of concepts. The theories above primarily address the tasks of answering questions about the analysis of concepts, along with the broadly epistemic questions about them … , while not always addressing the metaphysical questions directly. Yet the metaphysical issues do bear on the plausibility of one theory over another. As mentioned earlier, if concepts are abstract Platonistic entities, and not internal mental representations that are ‘in the head,’ then the classical view might escape some of the objections raised by prototype theorists. Alternatively, if concepts are ‘in the head’ as mental representations of some sort, and are structured in terms of the conditions one uses in sorting things as falling under that concept or not, then the classical theory looks bankrupt and the prototype theory looks superior to the rest. Whether the nature of a concept is to have
such structure, as opposed to classical structure, a structure more along the lines of the theory-theory, some other structure entirely, or no structure at all, is a thoroughly unresolved matter. 50

Recalling the above remark about the general scientific education of psychologists, one should not be surprised at how far from the physical reality all these theories of concepts are, and how scientifically immature they are. Also note a very typical for the overviews of the present theories of concepts and—they should be given credit for this—honest conclusion that everything is basically “a thoroughly unresolved matter”. Thus, again, we see quite disappointing results of the extensive attempts to deal with classes outside the context of the appropriate representational formalism.

8. Some of the secondary relatives of induction: Abstraction, abduction, universals and particulars

Abstraction comes from the Latin abstractio (detachment, division, retention), introduced by the Roman philosopher and theologian Boethius when translating Aristotle’s term aphièresis. Since the relevant to us meaning of the term abstraction has to do with the process of forming a general mental image of an object—note the root Form—we are entirely justified in interpreting this meaning as directly related to the process of induction. In that sense, abstraction is the process of forming the ‘idea’ of the class—via the class representation—on the basis of a small number of its members. So, although there are other uses of “abstraction”, in one sense, especially in science or philosophy, “induction” captures more accurately its meaning.

Moving on to abduction, it is the term introduced by Charles Peirce (1839–1914), possibly the greatest American philosopher, for the logical process that works in the direction opposite to deduction: inferring A from B, where A is a possible cause of B (there could be other causes for B). For example, if coming back home you found the grass to be wet, you conclude that it had rained. Over the years, Peirce also called the same process retroduction, hypothesis, and presumption.51 Moreover, Peirce suggests that abductive reasoning from B to A should involve not just the inference that B follows from A, but also that A is one of the most “economical” explanations of B.

The interesting question is this: Is abduction based on induction? It appears, without fully realizing it, Peirce himself gave a positive answer to the question when he admitted that the “first emergence of this new element [A] into consciousness must be regarded as a perceptive judgment”.52 It appears that what he calls abduction is, in fact, a logical elaboration of the results of “perceptive judgment”, i.e. of induction. I will address the central role of induction in the “perceptive judgment” in Chapter 9. Some researcher agree with this conclusion, see for example the view of Francis Reilly 53 or of John Holland and colleagues, who state that abduction is “induction in the service of explanation, in which a new empirical rule is created to render predictable what would otherwise be mysterious”. 54

Lastly, we deal with universals and particulars, a topic which dates back to at least Plato, but became increasingly prominent starting with the medieval philosophers—Porphyry (c. 232–305), Boethius (c. 475/480–524), Abelard (1079–1142), Aquinas (c. 1225–74), Duns Scotus (c. 1266–1308), Ockham (c. 1285–1349)—all the way to the present philosophers.55 Basically, a particular refers to a concrete object, while a universal refers to the characteristics—or properties, or features, or qualities, or attributes—that are shared by the particulars. So we are dealing with concrete objects and their features. Philosophers who believe in the reality of universals are “realists”, while those denying it are “nominalists”: nominalists believe that universals are just names that do not stand for anything
real, and hence deny the existence of Plato’s Forms. William of Ockham was a leading nominalist, while Peter Abelard tried to reconcile the two positions. It seems, the whole issue was sparked by one of the most known Greek realists, Plato, who advocated this position with such great literary talent.

From the ETS point of view, the situation becomes considerably simpler: we have classes and we have class representations. And the main question becomes this: Do class representations exist? If they do not, then, I claim, classes do not exist either. As far as this, more accurately stated, dilemma is concerned, I am, obviously, a realist. What have complicated the realist-nominalist debate are two issues. First, there has not been a clear conception of a class. And second, all these characteristics, properties, qualities, attributes, or features include those that exist, e.g. a cat’s tail or the overall shape of a galaxy, as well as those that do not, e.g. bachelor or beauty. A bachelor may become married at any time, without any fundamental change occurring in him, hence this is not a real feature, and beauty, as far as we know, is in the eyes of the beholder. It is possible that some so-called “universals” are unions, or collections, of classes. I also hinted in the middle of Section 5 that what one might call universals (albeit under a new name) are those features that can be extracted from the corresponding class representation. So again, the development of a satisfactory concept of class should put all these issues to rest.

9. The missing basic constituent of induction: What is a class?

The main test for any inductive formalism is the quality of the concept of class it affords. As far I am aware, so far, the only formalism that offers any reasonable concept of class at all is ETS. For this formalism, a more complete answer to what a class is has to be postponed until Chapter 13, after the necessary auxiliary concepts have been outlined. However, in this section, to give an intuitive idea of the proposed concept of class, I illustrate it by presenting a very simple example. In this section, I encourage you to slow down the pace of reading. By way of preparation, review Figures 1.5, 1.6 and note the following (informal) rule for attaching events in a struct. Whenever a new event is being attached to a struct, the types of the links that are being attached to each other must match, and not all the incoming links in the new event should be attached to some outgoing links in the struct.

Example: The PST world (PST stands for “points, segments, and triangles”). In this example, I discuss several very simple classes of 1- and 2-dimensional patterns in the 3-dimensional space. To keep the complexity under control, we restrict ourselves to the three basic formative events shown in Table 2.1. (All straight line segments can be replaced by the curved ones, without affecting anything.)

In general, when dealing with ‘engineering’ applications, it is useful to keep in mind that, for any concrete environment, we often have considerable freedom in the selection of the actual events involved. And so it is reasonable to assume that there might be several different (and acceptable) sets of basic events for that environment. Each of those sets of events, once adopted, offers its own version of how to view the formative object processes in that environment, i.e. the sequences of events that lead to the formation of objects in this environment. However, once the choice of the basic events has been made, the formative semantics of the objects is fixed.

Mindful of the needs of popular exposition, this preliminary, illustrative example—although I tried to preserve the spirit of the formalism—has to be quite simple. Also, to simplify drawings, all shown
### Basic events

<table>
<thead>
<tr>
<th>Basic events</th>
<th>A spatial instantiation of the events</th>
</tr>
</thead>
</table>
| ![Point](image1)  
| the unique *initial* event: creation of a point; since this event initiates the generative process, it has no incoming links;  
| this event does not have a label (which would be shown under the event) |
| ![Segment](image2)  
| the expansion of a point into a segment;  
| the right outgoing link in event P1 corresponds the newly created point and the left one, to the old |
| ![Triangle](image3)  
| the expansion of a segment into the triangle *by fixing one end of the segment and pivoting the other*;  
| the middle outgoing link in this event corresponds to the newly created point, while the left and the right outgoing links correspond to the left and right ends of the original segment |

**Table 2.1:** Three events involved in this example (the geometrical shapes of the events have no spatial connotation). Since the top event is allowed to occur only once, at the very beginning, focus on the next two events. The incoming (input) links of each of those events correspond to the processes acting on the previously instantiated extreme boundary points, while the outgoing (output) links correspond to the ‘new’ extreme points, which, in our example, *happen* to include the input ones. So when P1 or P2 is attached to any one of the above three events, the input point(s) are always ‘regenerated’ by this newly attached primitive and are “open for business” again.
event links are not differentiated (which calls for a little more attentive drawing of the structs). Moreover, given a somewhat artificial nature of the example, one should not read too much into the apparent coincidence of the event links with the conventional object ‘features’ (see Table 2.1).

Next, let us introduce three standard and convenient ETS terms: the incoming and outgoing event links will be called, respectively, initials and terminals, and the basic events themselves, primitive transformations, or simply primitives.

The first class we consider in the above PST environment is Segments, a member of which is shown in Figure 2.2 on the right. From the representational point of view (i.e. relying on the language of structs), its members are structs containing—besides the compulsory initial event—events P1 only. Since there are no other restrictions, and event P1 may occur any number of times, it is an infinite class. (Incidentally, while we are on the subject of infinite classes, it is quite possible that the finiteness of ‘physical’ objects in Nature might be ensured by the presence of special events.) Note that it is not difficult to turn the above verbal definition of the class Segments—and also each definition of classes in this section—into a more precise, stepwise, definition of the corresponding class representation (see the highlighted part at the beginning of Section 1.5): after the initial step, we have, basically, one repeatable step with the constraint admitting primitive P1 only.

When perceiving the resulting geometric configuration—and the configurations in the several following figures—one should keep in mind two points. First, the spatial orientations of the segments (and triangles) is irrelevant and, to avoid crowding, the construction can be thought of as occurring in the 3-dimensional space. Second, the semantics of the resulting geometric pattern has to be understood only via the above three basic events as they unfold temporally, rather than relying on any previous intuitive experience.

Now we come to a critical point: any one of our geometric patterns ‘hides’ many of its possible formative histories, or different generating processes. Thus, even in such very simple case, as shown in Figure 2.2, if we disregard the formative history (captured by the struct) we are permanently loosing important information. To illustrate this point, in Figure 2.3 you can see exactly the same geometric pattern but produced by a different generating process. Note that the two corresponding structs are quite different. So, is the formative history captured by the struct important?

Yes it is! Indeed, at a general level, as far as we know, all objects in Nature have emerged via various evolutionary processes and hence each object has its own formative history, outside the context of which it is meaningless. And for our concrete example, when we observe the process of generation for the pattern in Figure 2.2, we notice that this geometric pattern has an additional, underlying, generating pattern. It turns out that this generating process consists of a sequence of “branching” processes, where each branching process generates several (possibly none) segments with a common origin and the next branching process must now begin at the end of one of the segments just constructed. The only exception to this rule is the origin, to which the generating process is allowed to return at any time. In other words, the generating process must follow this simple branching logic. But for the generating process in Figure 2.3 this is not the case, even though it does produce the geometrically identical pattern.

Obviously, the more accurate formative information captured by a struct is an important part of the object generating process and hence of the object itself, but it remains inaccessible to the conventional forms of data representation. In fact, without the access to such information—even within such simple
Figure 2.2: **Left:** Pictorial depiction of a struct from the class *Segments*. The adjective “pictorial” is supposed to sensitize you to the basic fact that, as in the case of numbers, pictures are not the actual abstract representations. The numbers indicate the *order in which the events occurred*. **Right:** the actual object corresponding to this struct.

Figure 2.3: **Right:** The same object as in the last figure—which is, of course, also a member of the class *Segments*—but with the order of the events modified. **Left:** Pictorial depiction of the corresponding struct.
In connection with the above discussion, I should point out that the chosen primitives are not absolutely foolproof, since, as you might have noticed, the corresponding structs do not capture the complete formative histories. In particular, a part of the struct in Figure 2.2 (the events numbered 1, 2, 3, 4, 5) is identical to the same part of the struct in Figure 2.3 (the events numbered 1, 2, 3, 10, 12), even though each one fits differently into the overall temporal pattern: in the second case, events 10 and 12 occurred much later than events 4 and 5 in the first case. How can one address this situation? Quite easily and naturally, we can slightly comp lexify the primitives involved. Indeed, if such great precision in capturing the generative process is necessary, each primitive can be modified to have one extra initial and one extra terminal, where the new initial link in a primitive should be connected to the new terminal link from the primitive that immediate precedes it. In this way, the precise temporal information can be recorded by the struct. Obviously, such option is often unnecessary, in which case the added complexity considerably complicates the structs without any benefits in return. However, the above primitives do a reasonable job: for example, in Figure 2.2, the substruct formed by events 2, 3, 4, 5 is structurally identical to the substruct formed by events 6, 7, 8, 9, as are the corresponding geometric patterns.

Let us return to our original question: How would the induction work for the above class Segments? Of course, induction relies on the “training set”: a relatively small set of members of the class, “examples”, on the basis of which the class representation has to be derived and used for classification purposes. Without going into the technical details, it is not difficult to see how—given a sufficiently varied set of 10–20 examples, i.e. of the corresponding structs—the above mentioned class representation of Segments can be obtained. Indeed, as these structs will have all possible combinations of event P1, the only restriction for the same recurrent step in the class representation that will be learned from the training set is the ‘obvious’ one: apply primitive P1 only.

Of course, classes are ubiquitous. Even ignoring the formative history, class Segments has, among others, a very simple subclass, Roads: it is the set of all patterns in which each point can be shared by at most two segments. In other words, there are exactly two points—at each end of the pattern—that are not shared by two segments and any other point is shared by exactly two segments.

The next class we consider is Triangles: each object in this class is composed of triangles, with each pair of them sharing exactly one vertex (see Fig. 2.4). Note that in the shown geometric pattern, numbers next to a triangle’s side means that this side was generated before the triangle and was later expanded into the triangle itself. Again, observe the quality of the generative pattern capture by the struct on the left: for example, you can clearly see from the struct that the last triangle (17) was generated after triangles 15 and 16, or that triangle 5 is the only one spanning three triangles (7,8, 9).

I cannot help being inspired by the incredible possibility that when we are looking at structs like this we might be getting a glimpse of the beautiful and universal code of Nature, the truly primal language in which the ‘source code’ for each and every process is written. And when we see an object, what we see is an evolving instantiation in space of the corresponding process.

A more general pattern from the environment PST is shown in Figure 2.5. Observe, for example, that in the group of triangles 14, 15, 16, and 17 only one (14) was generated based on the previously
constructed segment (13), while the other three were generated from the sides of the previously generated triangles: primitive P2 can be attached directly to a previous primitive P2.

In Chapter 13, we will come back to the PST world and consider multilevel classes in it, when the higher level class elements are composed of the lower level ones.

Note that the PST world as a whole exhibits the following general, and somewhat ‘unnatural’, feature: any fixed existing point in the geometric pattern can be expanded into a segment an unlimited number of times, all sharing this point, and the same applies to any segment, which also can be expanded into a triangle an unlimited number of times, all sharing the same side. Also note that the two basic events involved are somewhat non-typical: as the pattern evolves, any of the two main primitives can be applied unlimited number of times at any ‘place’ they have been applied before,

**Figure 2.4:** Left: Pictorial depiction of a struct from the class Triangles. Numbers indicate the order in which the events occurred. Right: The corresponding actual (instantiated) object with the corresponding temporal order in its construction, where a number near a triangle’s side indicates the corresponding number for this segment, which was later expanded into that (adjacent) triangle.
since each of them does not transmute the place of application. It is in this sense that the primitives involved are relatively simple.

Before leaving this example, several important general observations and/or questions—to which we will come back in the last several chapters—are in order. The first one concerns the interpretation and the role of the structured events themselves. Recall what one of the leading mathematicians of the last century, David Hilbert, said about the axioms of geometry: that they are not about points, lines, and planes but about any objects satisfying them. As he put it “it must be possible to replace ‘point, line, and plane’ with ‘table, chair, and beer mug’ without … changing the validity of the theorems of geometry.” The same applies to events: they are quite universal, in the sense that their structure (not their spatial semantics) makes them applicable to many environments. For example, a more universal meaning of event P1 is that a single undifferentiated entity gives rise to two, possibly different undifferentiated entities, and such events abound in nature and non-scientific applications, e.g. think of the first cleavage of the embryo during its development, when one cell subdivides into two. Such considerations suggest that the number of basic, or elementary, events in Nature might be quite small, in fact, much smaller than the number of known elementary particles.

The second point was mentioned earlier, in Section 1.7, and is somewhat related to the first one: it is about the precedence of the structural representation over the spatial representation. In particular, since the events and the structs appear to be purely informational (with no spatial connotation) and have quite independent status: Is it not possible, first, that the existence of structs must precede the spatial existence of the corresponding objects, and second, that the class representations are stored (and dynamically modified) in Nature? One of the arguments in favor of this hypothesis is that all
known patterns reoccur regularly and this would not be possible without some ‘supervision’ of all the processes involved. If indeed this is the case, the spatial instantiation of objects, as was explained in Section 1.7, does not represent a difficult task, as the corresponding structs contain enough information to realize it.

Next, to get the feeling for the new scientific ‘language’, it is not difficult to visually generalize the above example: we need to increase the variety of primitives and of their possible interconnections.

Finally, note the significance of the proposed formative view of objects, the view that, so far—mainly because of the inadequacy of our representational means—has been neglected in science. (The reason Chomsky’s generative grammars had hardly any effect on science in general has to do with the lack of the corresponding representational formalism to support them.) In particular, even from the above, preliminary, example, it should not be difficult to grasp one of the main points in this book: since all objects have formative histories, the formative view of objects is their both principal and structural view, yet the numeric forms of representation are just not suited to deal with this view.

10. The unsuitability of human and logical languages as well as numeric formalisms to deal with the concept of class

On the basis of what we have discussed so far, you can safely assume that the topic of this chapter will be revisited again. However, in this brief section, we should draw some relevant conclusions from what was discussed in this chapter.

We saw in the first section how, during the development of logic, its founder Aristotle was led to the conclusion that induction is a powerful principle necessary as the foundation on top of which his logic can be built (see also the third epigraph to this chapter). Then, in Section 2, we saw how Hume, after analyzing induction—based on its verbal understanding—observed the apparently insurmountable obstacles in trying to understand it, which later on, during the last century, were turned into a tragicomedy (Sect. 5). The level of the obstacles can be judged by the fact that, as we will discuss in Chapter 8, even biologists for whom, one would think, the reality of classes, e.g. of species, in Nature is so critical, often go to a great length to evade it.

Thus, all philosophical difficulties in dealing with induction stemmed from the naïve misclassification of this problem as logical or philosophical, rather than a new kind of scientific problem. There was no realization that induction is about the classes of (mainly) real, as opposed to fictitious, objects and that the concept of class is a non-trivial concept that cannot be approached with ‘bare hands’, i.e. induction is above all a scientific problem, where we are entering a fundamentally new, information processing, science. In particular, the main and unrecognized difficulty appears to be related to the need for the new kind of scientific formalism within which the concept of class becomes transparent. But what kind of representational formalism (recall Sect. 1.1) do we need?

I believe, with Aristotle, that it is biology that should point the way: what it tells us about its objects should be true for all objects in Nature, since biological organisms are simply more sophisticated ‘versions’ of other objects. Note that the first and the main step towards the mind-matter duality, the main source of all our present scientific troubles, is the animate-inanimate duality. Moreover, as mentioned in Section 1.3, I do not think it is possible at all to ‘evolve’ during the biological evolution a fundamentally new form of representation: this is the task that no evolution can accomplish. But
biology—particularly developmental biology—suggests that objects have developmental, or formative, histories, and that the ‘glue’ that binds the objects into one class is directly related to their formative histories: the ‘closer’ their formative histories, the more similar the objects themselves are. Of course, this is not the place for a more formal elaboration of the concept of ‘closeness’ for the formative histories, but the important point is this: the formalism we are looking for should immediately explicate the concept of formative structure, i.e. it should embody this concept directly in the representation. Actually, for any representational formalism, including numeric, the representation that it offers comes with the unique—peculiar to that formalism—concept of formativity, or generativity, explicit in the way how the members of its representation set (Fig. 1.1) are constructed.

Thus, it should be clear that, first of all, any human or logical language is not suited for the purpose of capturing formative object histories so critical to the inductive considerations, hence all these ill-considered paradoxes discussed in Section 5. And second, the conventional, numeric, forms of data representation also cannot help us with induction, since the only kind of formative history a point in space embodies is this. For example, a two-dimensional point with coordinates (3, 4) was generated by ‘walking’ three steps along the first axis and then four steps parallel to the second axis. So if these two numbers represent the weight and the height of an object, how much of its formative history this point has captured? Indeed, how can this point in space convey the formative information (about the object) it has never had? Numbers were not ‘designed’ for the purpose of capturing non-trivial formative histories, end of story. Today, it is our fault that we stubbornly persist using the numeric representation as universal one and hope for the miracle. However, the good news is that, as we have glimpsed in the last section, the struct—or something like it—might well be the universal means for encoding the formative object structure.

Before concluding the chapter, let us critically evaluate the “poverty of the stimulus” argument introduced in linguistics by Noam Chomsky. The argument is that the grammar—that any of us is relying on when we exercise our mature language skills—is too complex to allow a child to learn it during the brief exposure to a relatively small number of sentences. On the basis of this argument, Chomsky, first, proposes that induction is irrelevant, and second, he proposes the “innateness hypothesis”, i.e. there exists a single “universal grammar” which is (genetically) innate to all of us. The second claim became quite controversial, since if accepted would lead to a host of similar hypotheses concerning other numerous areas of our expertise (mathematics, music, etc.). It is not difficult to see how Chomsky came to make such claim. Indeed, given the conventional forms of representation, the sentences a child hears are insufficient to deduce the underlying non-trivial generative patterns that Chomsky associates with our grammatical competence (see the end of Sect. 1.6). However, as the above simple example illustrates (Figs. 2.2–2.4), under the ETS representation, all previously hidden formative, or generative, information becomes explicit and hence the underlying generative pattern can now easily be learned based on a small set of examples (sentences), thus removing the need for the innate universal grammar.

Finally, I would like to draw your attention to the main reason why, quite unexpectedly to almost all scientists, induction is supposed to play the pivotal role in the coming radical scientific change. It appears that this reason is the absolutely indispensible role of structural representation in inductive processes, and in the concept of class of objects in particular. Of course, this is not to say that the structural representation is not useful for all fields.
Notes


5. Capital ‘F’ is to distinguish *Form* as *eidōs* (objective essence) from *form* as an appearance (*morphē*).


13. Francis Bacon, Novum Organum, LXI; see also CXXII: “For my way of discovering sciences goes far to level men's wit and leaves but little to individual excellence, because it performs everything by the surest rules and demonstrations.” http://www.constitution.org/bacon/nov_org.htm


23. Ibid., pp. 17–19.


29. For a somewhat humorous brief look at Popper’s personality, see the previous reference (Gardner basically belonged to Popper’s generation), [http://www.stephenjaygould.org/ctrl/gardner_popper.html](http://www.stephenjaygould.org/ctrl/gardner_popper.html).


31. See Note 28.


33. Ibid.


35. Ibid., p. 2.


37. See my paper in Note 4.


42. Ibid., pp. 10–11 (my translation from Russian).


49. Ibid.


---

### Useful terms

**epigraph** – a quotation placed at the beginning of a book or one of its parts to convey some relevant idea

**disjunction** – a basic logical operation on two statements A and B, A ∨ B (A OR B), whose value is FALSE only if both statements are FALSE

**query** – in information retrieval, it is a statement by a user of a particular request she/he would like to get from the database; typically, it does not uniquely identify a single object in the database

**record** – in information retrieval, a basic informational unit out of which a database is built (e.g. all information about an employee)
pattern recognition – ‘recognizing patterns’; the very first, and for a long time the only, field addressing various issues related to the theoretical and applied induction

machine learning – a newer and flashier version of pattern recognition, coming out of computer science, rather than engineering, milieu, as was the case with pattern recognition; hence the tendency to focus on more esoteric issues

artificial neural networks – another newer and flashier version of pattern recognition, initially coming out of psychological milieu and gaining quick prominence due to the unwarranted brain-related interpretations of the models they relied on; the basic model itself was a minor elaboration of the “perceptron”, one of the first models in pattern recognition

probability theory – the branch of mathematics concerned with modeling random phenomena; it is historically first attempt to deal with uncertainty, by assigning to an object a number between 0 and 1 indicating how probable or typical it is

vector space – an axiomatically defined concept that captures the idea of a multi-dimensional—sometimes, as in the case of Hilbert space (in quantum mechanics), even an infinite-dimensional—generalization of our three-dimensional space

potential and actual infinities – all of us are familiar with the concept of potential infinity, when some process of construction may go on indefinitely, as the process of constructing natural numbers; the actual infinity assumes that an infinite set exists not just via some unending process but given entirely as an actuality

concepts and categories – psychological term; concept is a mental representation of a class, while a category is the set of members of a class

primitive – a convenient term which refers to any one of the basic events in ETS formalism (so far we have been dealing with basic events only)

initials and terminals – respectively, the incoming and outgoing links in an event

training set – a set of members of a particular class, on the basis of which one is expected to form inductively the concept of that class

Basic points

- Aristotle, in contrast to practically all modern logicians—who continue to ignore induction—being the founder of logic, realized that propositional knowledge, i.e. knowledge expressed in propositions, is completely divorced from the physical world and hence needs some grounding. Moreover, he proposed that in attempting this, we should follow the way “sense-perception implants the universal”, and this is why he introduced the process of induction.

- Matter, according to Aristotle, is unrealized potentiality, and it is always and everywhere in process of organizing itself, i.e. acquiring various Forms. But matter completely disappears only when Form is fully realized and potentiality is resolved into actuality. Hence, Aristotle suggests,
pure actuality (information) contains no matter, and anything situated somewhere in space is ‘material’ (and not informational), because it might be somewhere else and still remain itself.

- Aristotle was trying to develop a general theory of the organism that would be extendable to the entire Cosmos, but the Scientific Revolution reversed this undertaking.

- Francis Bacon is particularly important since he was the only one among the founders of the “scientific method” who inverted the traditional priority of deduction over induction and insisted that induction is the foundation for the development of all sciences.

- Bacon also realized that a “greater labor will have to be spent in it [induction] than has hitherto been spent on the syllogism [logic].”

- Bacon foresaw that relying on induction as a general ‘tool’ will allow scientists to make great discoveries in a more routine manner.

- Although a number great scientists, including, Newton and Darwin, professed that in their work they followed true Baconian method, one should admit that so far we are left with the one-sided acceptance of his legacy, which completely ignores his advocacy of the developed induction as a powerful tool for the advancement of science.

- The first prominent attempt to deal with the issues related to the justification of induction was that of David Hume. But the results, not surprisingly, were disappointing: induction is ubiquitous but why it should be true is not clear at all, except for one principle that he proposed which was later called the “uniformity of nature”.

- Unfortunately, in the 20th century, Hume’s unsuccessful attempt to find a ‘rational’ justification of induction was often seen as a proof of its non-existence.

- During the first decade of the 20th century, the greatest at that time mathematician Henri Poincaré was engaged in a debate with the logicists—the group of mathematicians and logicians, including Peano, Russell, Zermelo, and Hilbert—whose aim was to found mathematics entirely on logic, i.e. on very simple and very transparent (symbolic) principles, which, of course, excluded induction. His conclusion was:

And in proof itself logic is not all. The real mathematical reasoning is a true induction … All the efforts that have been made to upset this order, and to reduce mathematical induction to the rules of logic, have ended in failure, [which is] but poorly disguised by the use of a language inaccessible to the uninitiated.

- The transitional 20th century has witnessed a tragicomedy of induction: the increasing number of philosophical attacks on induction, and at the same time, for the first time in history, the emergence of technologically driven enormous demand on induction.

- Induction, if properly developed, should unrecognizably transform all search engines as we know them today: in response to your query, you should get a much more selective set of records that match you query semantically, i.e. based on its content, rather than relying just on some words or phrases in it, as it is done today.

- Excluding ETS, so far, despite the enormous investment of money and human resources, no fundamentally new general scientific ideas regarding the nature of induction were discovered or
even proposed, with one, almost forgotten, exception of syntactic pattern recognition, which was inspired by Chomsky’s generative grammars.

- It is unreasonable to expect the probability theory to perform the miracle: *the information that is missing from the numeric object representation cannot be recovered by any analytical means.*

- One of the greatest scientists of the second half of the 19th century, Hermann von Helmholtz, concluded about induction:
  
  Inductive inferences, executed by the unconscious activity of memory, play a commanding part …
  
  It may be doubted that there is any indication whatsoever of any other source or origin for the ideas possessed by a mature individual.

- The extensive cognitive science research into concepts (i.e. classes) is at an impasse: the nature of concepts “is a thoroughly unresolved matter”.

- With the development of induction, such concepts as abstraction, abduction, universals and particulars will wither away, since classes and induction will make them obsolete.

- The main test for any inductive formalism is the quality of the concept of class it affords. As far I am aware, the only formalism that offers *any reasonable concept of class* at all is ETS.

- In section 9, a simple example illustrates the idea of ETS representation and why it should play an important role in the construction of the class representation during inductive learning. In particular, Figures 2.3 and 2.4 illustrate the following critical point. Any ‘visible’ pattern hides many of its possible formative histories, or its different generating processes. And the latter are lost permanently, if the chosen object representation, e.g. numeric representation, is not capable of capturing this, as I claim, primary side of reality. In particular, the examples illustrate that under a non-structural representation we are missing many classes of objects, i.e. they become invisible.

- Thus, already in this chapter, we begin to see why the generative side of objects is so crucial and hence should be captured by the object representation, hence the need for a structural representation. The reason all historical attempts to deal with induction have failed has to do precisely with the inability of a spoken language or the numeric formalism to capture that—generative and primary—side of reality.
Chapter 3

The temporal origin and the temporal axiomatic structure of natural numbers

Our instruments of detection and measurement, which we have been trained to regard as refined extensions of our senses, are they not like loaded dice, charged as they are with preconceived notions concerning the very things which we are seeking to determine? Is not our scientific knowledge a colossal, even though unconscious, attempt to counterfeit by number the . . . world disclosed to our senses?

Tobias Dantzig

The whole is more than the sum of its parts.

Aristotle

I'm writing a book. I've got the page numbers done.

Stephen Wright

1. Before numbers: Counting and four stages in the emergence of natural numbers

In this very brief but important chapter I address three issues: the temporal origin of natural numbers, the temporal structure of their formal definition, and the gradual displacement of their temporal structure by the spatial structure during the emergence and spread of various measurement practices. The last topic will be treated more fully in the next chapter.

In this section, we consider the process of emergence of the natural number concept. The first stage in this process is briefly captured in 1:

When a primitive hunter wanted to know if all the dogs in his pack are present he did not count them but simply glanced at the pack to see which one was missing. Such “perceptual count”, accessible even to a duck which is aware if all her brood is following her to a pond, existed long before the emergence of counting.

This, perceptual, estimate most likely involves two kinds of comparisons: the search for each individual object (e.g. a missing dog), and the gestalt, or the overall, comparison of the two groups of objects (e.g. *** vs.  • • • • •). Both processes rely on our main perceptual, or pattern recognition, mechanism.

The second stage in the emergence of the natural number concept is characterized by the choice of several ‘standard’, or reference, groups of objects, e.g. fingers, bone notches, thread knots, sticks, stones, multi-shaped tokens, and the goods exchanged in barter. And already here, I wish to draw your attention to one important—and so obvious that we tend to ignore it—aspect of counting, the
temporal aspect, which has not yet been appreciated adequately and to which we will come back in the next section. In particular, note that even at these, earliest, stages, a somewhat implicit *temporal aspect of counting* is actually the dominant one.

The next, *third*, stage, follows quite naturally from the second one and involves a drastic reduction in the number of selected during the second stage ‘standard’ sets of objects. For example, for trade purposes, one can select a reference set of objects in the form of standard silver and gold weights (later becoming coins).

During the *fourth stage*, we see a very gradual emergence of the *abstract* concept of natural number, which is not tied to any concrete set of reference objects and which is reinforced by the corresponding words and later by the appropriate signs, or symbols. It is this stage that is mainly responsible for the *contraction* of the initial *temporally and spatially extended denotation* of a number—such as a series of bone notches or thread knots (second stage)—into a single symbol signifying the corresponding abstract concept. What most likely finalized this process of number abstraction are the development of extensive and intensive trade relations, with the accompanying intensification of the use of money, and also the spread of various measurement practices.

In connection with the last, fourth, stage, note that even modern mathematics ‘admits’ the infeasibility of the reduction of the concept of number to a symbol: according to Frege-Russell definition², a number is defined as the set of all sets having the same size (cardinality): e.g. number “two” is defined as *the set of all sets* each containing exactly two elements, which is obviously an infinite set. Thus, despite the appearances, we must accept quite abstract nature of the concept of number and acknowledge the artificial nature of its reduction to a symbol, which is the situation similar to most symbols we use (the word “cat” signifies an unbounded number of cats).

As time progressed, we can also trace the process of blurring between the *ordinal* and *cardinal* meanings of a natural number, where the ordinal ‘meaning’ of a natural number refers to its *position in the ordered set* of natural numbers (related to its temporal origin), while its cardinal ‘meaning’ refers to this number as capturing the *size* of the corresponding set of objects. As we will see in the following chapters, such developments marked the beginning of the very long process of subordination of the number concept to increasingly more and more abstract yet *spatially motivated conceptual schemes far removed from its original temporal connotation*.

### 2. The temporal origin of natural numbers and their modern axiomatic definition

The main objective of this section is to bring out the intrinsically temporal nature of both the informal and the formal concepts of natural number, where the formal concept is considered to be the most basic (and a most satisfactory) definition in mathematics. Of course, we should take the need to rely on the temporal construction in such basic definition as quite significant.

Let us first deal with the following question: What are the *perceptual* processes responsible for the emergence and development of counting? It seems that the only serious candidate is the *central* perceptual process, i.e. the pattern recognition process, responsible for our orientation in the environment and intimately related to the inductive process discussed in the previous chapters. Since *all organisms* rely on pattern recognition, or classification, processes for their orientation in the environment, and—as I have argued in the previous chapters (and will do so in the future ones)—the
representations used by such processes are of temporal nature, one would expect that some animals and birds should possess the rudiments of counting capability. And indeed, this turns out to be the case, as the following several, out of many known, examples testify.

Thus, rhesus monkeys can match the number of sounds they hear to the number of shapes they see, “proving they can do math across different senses”. 3 The cormorants are a bird family used by Chinese fishermen for catching fish by using a ring on their neck and allowing each of them to eat every eighth fish as a reward. It was then observed that “once their quota of seven fish was filled, the birds ‘stubbornly refuse to move again until their neck ring is loosened. They ignore an order to dive and even resist a rough push or a knock, sitting glum and motionless on their perches.’ Meanwhile, other birds that had not filled their quotas continued to catch fish as usual.” 4 Irene Pepperberg of MIT, famous for her 30-year work with parrot Alex—who could among many, much more remarkable, feats count up to six—observes: “So some degree of ‘number sense’ seems to be able to be learned even in invertebrates, and such learning is unlikely without some underlying neural architecture on which it is based.” 5 Obviously, in all such cases, we cannot speak of any presence of the number concept, but what one can claim is that, in each case, the biological organism is capable of representing the corresponding sequence of events.

Next, by way of preparation for the following formal definition of natural numbers, let us, again, try to discern the principal role of temporal representations in the above second, and in a sense the key, stage in the development of our counting capabilities (last section). To this end, it is enough to pick one out of the above several reference groups of objects, e.g. bone notches, and analyze the process how they were actually produced. For every such sequence of bone notches, what really happened is that to each observed object, e.g. an animal, we assign, in a temporal mode, a single reference object, a bone notch, and carve it, so that at the end of the process we have a (temporally produced) sequence of notches. In other words, one, first, observes some complex event, and then one records it, in a simplified manner, by the corresponding bone notch. Outside this temporal process of construction, natural numbers loose, and in fact have lost, their proper interpretation. Actually, as I emphasized in the first chapter, without exception, all processes in nature, and not just the process of productions of bone notches, are of temporal nature. The only reason I try to draw attention here to the temporal nature of natural numbers is that, thanks to the dominance of spatial considerations in the development of mathematics, this obvious point has been suppressed.

And now we are ready to consider the Dedekind-Peano—or simply Peano (under which name they are more known)—axioms for natural numbers. The set \( N \) of natural numbers is defined as a set of elements satisfying the following axioms, or postulates:

1. \( 1 \) is an element of \( N \).
2. For each natural number \( n \) there exists (among natural numbers) the unique successor \( n^+ \), distinct from \( n \), such that if for some natural number \( m \)
   \[ n^+ = m^+ \text{, then } n = m. \]
3. \( 1 \) is not the successor of any natural number, i.e. there is no natural number \( n \) such that \( n^+ = 1 \).
4. (The axiom of induction) If some subset \( M \) of natural numbers contains both \( 1 \) and the successor of every number in \( M \), then \( M \) must coincide with the entire \( N \).
The second axiom is typically split into two axioms. Also, from this axiom it follows that the set $N$ of natural numbers is infinite: otherwise the successor of its largest number would not be in that set, violating the axiom.

More importantly, observe the special status of the axiom of induction, which differs substantially from the other axioms, both in appearance and substance. It differs in appearance since it is about special kind of subsets of $N$. As emphasized by the great mathematician Henri Poincaré (see Sect. 2.4), the substance of this axiom is critical to the entire edifice of mathematics, and hence to science in general:

*Without the aid of this induction, which in certain respects differs from, but is as fruitful as, physical induction, construction would be powerless to create science.* [My italics] \(^6\)

and

*All the efforts that have been made . . . to reduce mathematical induction to the rules of logic, have ended in failure, [which is] but poorly disguised by the use of a language inaccessible to the uninitiated.* [My italics] \(^7\)

However, as I mentioned above, one of the objectives of this section is to draw attention to the explicit temporal nature of the above definition, i.e. its actual reliance on the successor operation $S$ assigning to each number $n$ its successor $S(n) = n^+$. To simplify the exposition, I avoided the explicit use of the successor operation and used instead the notation $n^+$, while more formal expositions of the Peano axioms explicitly use this successor operation. In any case, the inevitable reliance of the formal definition on this operation is a clear admission that the corresponding temporal process of construction (Fig. 3.1) is the quintessence of the natural number concept.

![Figure 3.1: Pictorial illustration of the temporal (Dedekind-Peano) structure of natural numbers.](image)

3. **The role of various geometric constructions in our culture and science**

Now we come to a historical event that, in retrospect, appears to have played an important role in the chain of events responsible for the permanent spatialization of numbers, where the latter was ‘officially inaugurated’ in modern science much later by the Descartes coordinate system and by what was later called analytic geometry. Since the latter developments will be addressed in Chapters 4 and 6, we mention here one of the triggering events, the discovery by Pythagoreans—and quite possibly even earlier by other cultures—of the non-commensurability, in a unit square, of its diagonal with its
side, or in the modern language, the irrationality of \( \sqrt{2} \): the length of the diagonal \( d \) is equal to the square root of \( a^2 + b^2 \), where \( a = b = 1 \) are the adjacent sides of the unit square.

In this connection, it is important to note that the way irrational numbers came into mathematics is via geometric, or again spatial, route. Of course, at that time, in view of the dominant role of spatial measurements in various cultures, no one would question the expediency of this step. Moreover, what is more significant is that even today the same expediency, or logic, applies, in the sense that we do not question this rational: the square and its diagonal must exist as physical entities, and a very natural question “Why must they exist as a part of physical reality?” is hardly asked today. This should illustrate how deeply, over the last several millennia, our spatial constructions became entrenched in our minds, which is not difficult to understand if one is aware of the critical role such geometric constructions played in the development of early mathematical knowledge and of our culture in general. Indeed, as was recently discovered, various geometric constructions played an important part in the ritual knowledge, starting from “the Neolithic age, say between 3000 and 2500 B.C., and spread from Central Europe to Great Britain [Stonehenge], to the Near East, to India, and to China.”

4. Conclusions: The origin of the historically inevitable displacement of the temporal by the spatial

The driving force behind the displacement is this: the intricate geometric constructions complemented by numeric calculations—first used for setting up various rituals and then, much more intensively and extensively, used in various measurement practices, including construction of temples—formed the core of the emerging formal “language” for expressing more accurately our knowledge about the external world. Of course, it was the sense of sight, our by far the most powerful sense, that guided and promoted all such processes, including an acceptance of various geometric constructions as physically real entities.

As will be discussed in the next chapter, eventually, the fathers of the Scientific Revolution decided to remove completely any lingering intuitions about the important role of the mental as an obstacle to the development of spatially-based science, i.e. science based on the formal language motivated by various geometric considerations.

Thus, the present absolute dominance of spatial considerations in science should not come as a surprise, as indeed captured by Einstein in the quotation given in the middle of Section 1.8 that “natural science . . . endeavors in principle to make do with ‘space-like’ concepts alone, and strives to express with their aid all relations having the form of laws.”

Returning to the main topic of this chapter, why is it important to keep in mind the temporal origin and temporal structure of numbers? Although this issue is related to the main theme of the book, here I wish to draw your attention, again, to the present situation with the yet unrecognized unprecedented crisis in science. This crisis is, in fact, the result of the accumulated “negative” side effects of a long process of subordination of the number concept to increasingly more and more abstract conceptual schemes that are far removed from its original temporal connotation. In other words, despite the enormous success of science, by treating the number outside its temporal context, we have emasculated and distorted its true ‘meaning’ and have been unable to deal adequately with the (central) issue of time. So that when the concept of number has been repeatedly generalized during
the last several centuries, the disregard for the precedence of its temporal nature over the spatial one has propagated this basic inadequacy residing in the very heart of our present mathematics and, obviously, has had enormous implications for our perception of ‘physical’ reality. The one-sided perception, discussed throughout the book, has evolved on the bases of non-temporal, spatial, side of that reality, while its temporal—and I dare to suggest much more fundamental (because of the evolving nature of the Universe)—side remained hidden. Of course, the capability to approach a temporally adequate generalization of the number concept, à la ETS struct (see Sect. 1.4), could have emerged only within the last century, but now it is long overdue.

At present, given our collective scientific experience, the temporal may appear to be more abstract and less scientifically ‘familiar’ than the spatial. However, since we are now increasingly faced with the demands of information processing—which, most likely, cannot be understood as part of the familiar to us spatial reality—we have no choice but to address the temporal scientifically. And it seems quite natural that—as was the case with the series of spatial generalizations of numbers—now is the time to return all the way to the primordial origin of our scientific journey, the concept of natural number, and to focus on the (temporal) generalization of its temporal structure, which may show us the way out of the spatially-based science.
Notes


3. Michael Tennesen, More animals seem to have some ability to count: Counting may be innate in many species, Scientific American, Sept. 15, 2009, http://www.scientificamerican.com/article.cfm?id=how-animals-have-the-ability-to-count


5. See note 3.


Basic points

- The underlying structure of natural numbers—both as they emerged historically and as they are defined axiomatically (by Peano axioms)—is temporal.

- It was recently discovered that various geometric constructions played an important part in the ritual knowledge, starting from the Neolithic age, say between 3000 and 2500 B.C., and spreading from Central Europe to Great Britain (Stonehenge), to the Near East, to India, and to China. This further clarifies the reasons for the central role of geometric, or spatial, considerations both in our culture and science.

- Facing the information-processing age, how can we free ourselves from this historical ‘bondage’ to the centrality of spatial considerations? It may seem paradoxical, but in fact it is quite ‘logical’ that the only way we probably have out of the spatially-based science is by returning to the absolute foundation of our science, the natural numbers, and trying to generalize their temporal structure, as this is done, for example, in the concept of struct (see Sect. 1.4).
Chapter 4

The die has been cast: The inevitable and fateful philosophical and scientific decisions by the fathers of the Scientific Revolution

1. The overlooked first and most remarkable scientific revolution: The emergence of science in the 6th–3rd centuries B.C.

2. Discovering the ‘sinful’ path out of the Dark Ages: Quantification of Western society in 13th–16th centuries

3. The beginnings of the measurement madness

4. Some fathers of the Scientific Revolution: Galileo, Kepler, Descartes, Newton, and Leibnitz

5. The dominant role of space: Spatial extension as the essence of material substance

6. The homogeneity and immutability of the Euclidean (Cartesian) space

7. Matter as structureless substance not subject to becoming

8. Elimination of the Mind as a non-spatially extended entity

9. The motion as a simple change of place under the external ‘mover’

10. The concept of force: The external mover and the resulting matter-force dualism

11. The implicit elimination of time: Its subordination to the concepts of space, matter, and motion

12. The corpuscular-kinetic view of Nature

13. Numeric mathematics as the divine tool for organizing the Universe
Chapter 5

The accompanying radical dualism

1. Matter as radically non-mental or mechanical
2. Nature as the product of the transcendent immaterial God
3. No place for our minds in the ‘grandiose’ scheme of things
4. The emergence of our insignificance
Chapter 6
The spatial basis of the resulting formalism

1. The continuation of the Hellenistic mathematics
2. The fusion of algebra and geometry by Descartes
3. Our basic representational formalism: The (Euclidean) vector space
4. The development of infinitesimal calculus
5. The (instantaneous) velocity and acceleration and their fictitious character
6. The mathematics of motion: Differential equations
7. The development of differential geometry
8. Besides introducing the idea of non-commensurability, complex numbers have hardly improved the representational power of the numeric formalism
9. The development of algebra in the 19th century and the present popular illusion of its independence from the spatial considerations
10. The consolidation of the spatial view of reality: The concept of set as the foundation of modern mathematics
11. The generalized concept of space: Topological space
12. The lack of the concept of structural representation in mathematics
Chapter 7

Some consequences of building physics on the spatial foundation

1. Physics as a science of motion (in space) and its profound effects on our culture
   The role of Laplace in the separation of physics (science) from the “reality”

2. The adventures of the concept of force

3. The modern concept of field and the practical elimination of the atomic hypothesis

4. Minkowski space of special relativity: Time is non-commensurable with space

5. The ambiguity of the concept of mass in special relativity

6. Quantum mechanics: Continuous formalism for a discrete phenomenon
   quantum indeterminacy relations as invalidating the physical applicability of the differential-integral framework;
   indeterminacy as invalidating the concept of quantity of any kind at the quantum level

8. Chronon and hodon: Desperate and not meaningful attempts to address the observed discreteness of Nature

9. Group theory to the rescue

10. Flirting with the mind: The consequences of the mind-matter split for quantum mechanics

11. The show must go on: Old physical concepts but imbued with new meanings

12. The misleading use of “information” in physics

13. The misleadingly central role of the second law of thermodynamics and of the entropic processes in physics

14. The dark matter and dark energy

15. Despite all the “unifications”, the unification with the mind is not even on the agenda

16. The fundamentally reductionist orientation of physics

17. Why education in physics may actually be a hindrance for developing new ‘physics’
Chapter 8

Some consequences of basing other natural sciences on the spatial foundation

1. The inherited fundamentally reductionist orientation of all natural sciences

2. A very peculiar state of chemistry: dealing with structures without structural representation

3. An even more unnatural state of biology: dealing with evolution and development without a formal language for recording the past

4. Why biology cannot mature without the clarification of the species concept
   Including: the great length to which some biologists go to deny the reality of classes in Nature

5. The misleadingly central role of the second law of thermodynamics and of the entropic processes in chemistry and biology

6. The artificial pyramid of sciences with physics at its base
Chapter 9

The turtle-paced development of psychology and cognitive science in general

1. The consequences of the mind-matter split for psychology and the emergence of cognitive science
2. The indefinite status of concepts and categories in psychology and cognitive science
3. The lack of a unifying basis for neuroscience and perception
4. The inadequate integration of perception in psychology
5. Why Chomsky’s concept of generativity could not sufficiently influence the development of cognitive science
Chapter 10

The false expectations of computer science

1. The origins of computer science in logic
2. No commitment to a representation
3. Computation instead of information processing
4. The general search problem as a professional obsession substituting for ‘intelligent’ database organization
5. Why Google made it so big so quickly: Noticing the obvious
6. The amazingly immature development of artificial intelligence
Chapter 11

Some important features of reality coming into focus during the last century

1. The process view of reality: Hegel, Bergson, Whitehead, and Čapek

2. The importance of formative history: Developmental biology

3. Sheldrake’s hypothesis of formative causation

4. The importance of ‘history’: Giambattista Vico and Roger Collingwood

5. The need to address the organizing principles in physics and biology: Lancelot Law Whyte

6. Chomsky’s concept of generative grammar

7. ‘Structural’ pattern recognition

8. The notion of emergence
Volume II

Chapter 12

Is there a different mathematics, mathematics of the mind?
Structural representation

1. What should information processing be about?
2. The need to brake with the conventional, spatial, forms of representation
3. The basic structural units: Primitive events
4. The structural representation of a process: The (level 0) struct
5. The struct as a record of the formative history
6. The basic operation on structs: Struct assembly
7. The concept of structural constraint (at level 0) as a means of specifying a family of related structs
Chapter 13

The inseparable concepts of class and class representation

1. A single-level class and its representation
2. Level 1 structs
3. A two-level class and its representation
4. Level 2 structs
5. Higher-level class representations
6. An illustrative example
7. On the nature of instantiation
8. Some implications for developmental and evolutionary biology
9. One possible side of the emergence
Chapter 14
Transformations and representational stages

1. The macro-analogues of primitive events: Transformations
2. A multi-stage structural representation
3. Another possible side of the emergence
Chapter 15

Two main bonuses: The disappearance of the mind-matter split and the unity of syntax and semantics

1. The subjective struct as an agent’s representation of an object and the objective struct as the Nature’s representation of an object
2. The amazing unity of syntax and semantics
3. Some implications for science
4. The new radically simplified epistemology
Chapter 16

The structural, or temporal, view of reality and the natural sciences

1. The primary role of ‘structures’ in the Universe

2. The importance of dealing with structures directly in the representation, rather than indirectly, as in the present mathematics

3. The transition from the spatial, or numeric, representation to the temporal, or structural representation

4. The structural measurement processes

5. Physics: From motion to information and structure

6. No need for the mysterious wave-particle duality

7. A few words about the new, structural, chemistry

8. The new, structural, biology

9. No pyramid of sciences
Chapter 17

The new information processing science

1. Mirroring the Nature: Classes as the basis for information organization and processing

2. How to get bigger and better than Google: New kind of databases and search engines

3. The last programming language

4. What is this thing which was called ‘hardware’?
Chapter 18

Conclusion: We are about to embark on our greatest adventure

1. But first, we need to learn how to use this new language
2. This is just the very beginning of a new scientific language
3. The new scientific outlook should catalyze the social transition