IS THERE A COMMON STRUCTURING LAW IN THE UNIVERSE?

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)

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All comments are gratefully appreciated (goldfarb 'at' unb 'dot' ca)

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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

> … 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 why, to meet the needs of the *coming* Information Age, we should be ready for the most radical (which is only to be expected) shift in science: from numbers to some other, more intricate, entities. Yet not many expect *that* kind of shift. So the central issue is that of *data representation* in, and outside, science, including *what* "data" is and *how* we collect and interpret it.

Thinking of "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 formal 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 addressed in the book should open for us.

Let us fix the term **scientific**, or **representational**, **formalism** for the concept that includes, first and foremost, some *basic form of data representation*—that is, the chosen *representation set* (Fig. 1.1)—and second, the accompanying formal apparatus supporting this form of data representation. Such formalism is the compulsory 'spectacles' one must wear *in order to collect and process any data*. As just mentioned, the first of these two, and the one presently taken-for-granted, component of the formalism is its **representation set** (Fig. 1.1): the set of abstract entities carefully constructed at the very beginning, once and for all, *to represent, or stand for*, the "real" objects. (I use the noun "object"

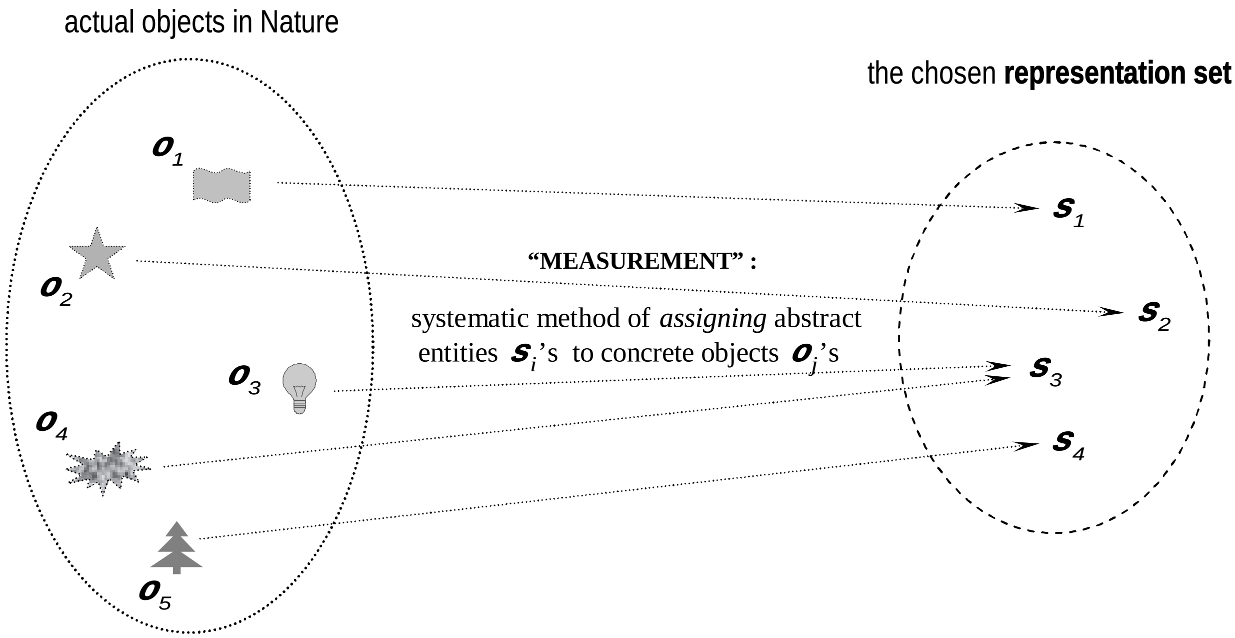


Figure 1.1: The concept of a representation set: each $\boldsymbol{s}_i$ (i = 1, 2, 3, …) is *systematically constructed to 'represent'* the object $\boldsymbol{o}_j$ on the left and is then assigned to it. Important: $\boldsymbol{s}_i$ *does not have to be a point in* a numeric or even in a more abstract *space*, as has been assumed so far.

in the most abstract and widest possible sense, which includes "process".) Here is the key point: we need to generalize the ever-present situation in science involving *solely* the numeric form of data representation, i.e. we need to allow the above "abstract entities" to be *of non-numeric origin*!

As we well know (Chs. 3–8), our science has relied on *a single* basic representational formalism—associated with the numeric measurement processes—which goes back to the origins of the human civilization and which has never been challenged. I will call that formalism, including its extensions, **the numeric formalism.** In it, numbers and, later, *a variety* of numeric constructions—e.g. complex numbers, vectors, matrices—serve as 'parts' of the above representation set, i.e. we *represent* actual objects by means of such kinds of numeric entities. In the typical applied case, 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, direction, size, mass, speed, brightness, temperature, 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] [1]

Indeed, our scientific and everyday lives are dominated by the questions "how much", "how big", "how small", "how long", "how heavy", etc. In this regard, not much 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', or the corresponding *"pattern"*. Historically, many sages have agreed that such patterns are of qualitative rather than of quantitative, or numeric, nature, where "quality" and "quantity" might be considered antonyms. Not surprisingly, after the Scientific Revolution, the noun “quality” has been expunge from the scientific vocabulary. In this book, I outline a new scientific view that suggests, in particular, that not only our perception, but Nature as a whole, might actually rely on a *non-numeric* form of representation.

The present numeric form of data representation was sanctioned during the *Scientific Revolution*, mainly of the 17th–18th centuries, but it was prepared by the previous three-four centuries of the *historically unprecedented general cultural shift from the qualitative to quantitative (numeric) perception in Western Europe* (Ch. 4). The shift was even more pervasive 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), musical notation, and architecture.[2] Of course, the Scientific Revolution itself was the *continuation* of the taken-for-granted Greek scientific revolution (Sect. 4.1), whose achievements were rediscovered by the Europeans during the above “shift” centuries. So one might say that, under the emerged *quantification* culture, the Scientific Revolution of the Early Modern period built the numeric ‘train’, the numeric ‘rails’ for which were built by the earlier, Greek, scientific revolution.

Given the pervasiveness of our *numeric* culture, the issue of *non-numeric* forms of object representation could not have arisen within it. Only the growing role of computers brought to the attention of computer scientists and psychologists the neglected general topic of *object representation*, particularly in the computer and, unavoidably, in the mind. This topic is addressed throughout the book, but for now—in the way of preparing you for the inevitability of the impending, historically unprecedented, scientific transition—I draw your attention to the following, very important, point by a leading mathematician of the last century, the polymath John von Neumann. Subsequent to his pioneering work on the development of modern computers, his very last effort in modeling the mind appeared as the (unfinished) lectures *The Computer and the Brain* (1958), with this conclusion in the last section of the book titled “The Language of the Brain [Is] Not the Language of Mathematics”:

> Just as languages like Greek or Sanskrit are historical [i.e. incidental] facts and not absolute logical necessities, it is only reasonable to assume that logics and mathematics are similarly historical, accidental forms of expression. They may have essential variants, i.e. they may exist in other forms than the ones to which we are accustomed. Indeed, the nature of the central nervous system and of the message systems that it transmits indicate positively that this is so. … [The conclusion of the lectures:] *Thus logics and mathematics in the central nervous system, when viewed as languages, must structurally be essentially different from those languages to which our common [scientific] experience refers.* [My italics, pp. 81–82]

Accordingly, in the main part of the book, I discuss the structure and the *inherent*—i.e. related to its *formal* structure—limitations of the numeric form of object representation (where s_i in Fig. 1.1 is a *point in some space*). Such numeric representations plus the scientific focus on the (spatial) object motion in the 17th–18th centuries have shaped the development of mathematics, physics, and, eventually, of all data processing fields. I will argue that, today, it is this ubiquitous, spatial (point-based), form of data representation that is responsible for a one-sided and progressively confusing view of Nature coming out of physics and other sciences, including information processing fields.

The use of numbers has been an ever-expanding affair: from *the temporal*[3] *origin of natural numbers*, discussed in Chapter 3, to counting, to measuring, and eventually to *object representation* (via numeric coordinates). It is the latter, as we will see, that is the main culprit. Its roots can be traced to the unavoidable gradual shift—starting with the ancient measurement practices—from the above temporal to the *geometric*, or *spatial*, considerations. I will argue that a systematic use of numbers for *representing* objects in some *space* began with the Scientific Revolution, based on quite productive *at the time* spatial view of objects, as composed of "points". (Incidentally, the Pythagoreans are not to 'blame' for this, since they had a more abstract, 'structural', view of objects.)

We will see in Chapter 3 that the natural number—both as it *initially* emerged and as it is now treated axiomatically in mathematics—is a *temporal* concept (Fig. 1.4). Note that the original use of numbers for counting and their later use driven by the emerging ancient trade and economic relations had hardly any *spatial* connotations for *object representation*; and only following the Renaissance rise of quantification culture (Ch. 4), the protagonists of the Scientific Revolution initiated, with a remarkable genius, the systematic use of numbers for representing objects/processes in a "multi-dimensional" *space* (Fig. 1.1). What is more, in time, *all formal machinery in science* has evolved to support the legitimacy of the emerged spatial "reality" only. As a result, presently, we have no formal means of approaching the informational (non-spatial) side of processes in Nature.

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. In the end, the *temporal origin* of natural numbers was *completely* overridden by the *spatial* connotation of this, much larger, set of numbers (reals). Quite understandably, time itself was turned into an extra *spatial* dimension and hence, effectively and rather conveniently, emasculated (Chs. 5, 7, 8).

Eventually, in the hart of modern physics, in quantum mechanics, we have run into *basic* conceptual difficulties: experimentally observed *"discrete"* underlying reality had to be forced into a *continuous* formalism, *the only one we have had to rely on*. (In fact, there is no experimental means to support the claim of continuity of *any* entity.) This predicament is a result of *a purely calculational*—or the famed "shut up and calculate" [4]—orientation of the numeric formalism. The situation has its roots in the inherently inconsistent state of affairs in physics and chemistry, where universally accepted *atomistic*, or "discontinuous", view of Nature[5] coexists with the ubiquitous *continuous* formalism, e.g. calculus, geometry, topology. As I discuss in the following sections, the true scientific limitations of the numeric representation could not have come into sight within the natural sciences, in view of how they evolved. These *inherent* limitations come to the fore when we attempt to model the 'intelligent' information processing, and *inductive processes* in particular (Sect. 4).

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".

2. Is there a form of data representation fundamentally different from the numeric (preliminary considerations)?

Today, at the onset of the Information Age, there are serious reasons to rethink the central role of numbers, numeric measurements, and of the spatial considerations in science, where it is the latter, as we will see, have driven the development of mathematics and science. I will argue that it is *the informational* considerations, *understood in a novel way*, that compel us to shift from the numeric to a much richer, *structural*, form of object (data) representation. Moreover, since the informational is our *last* scientific frontier, we should expect from the new form of data representation, *from the very outset*, at least some indication as to the missing (in science) source of ‘spirituality’ in Nature. So the questions I have been working on since 1980s are these: How can we move beyond the numeric formalism? and What will the Nature look like through the new, non-numeric, ‘spectacles’?

Note that, independent of the information processing demands, the greatest *possible* expansion of our scientific horizon is *also* achieved through the transition to a non-numeric form of representation: no *fundamentally* new form of data representation—no fundamentally new view of Nature. No other way *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 is being collected, stored, and processed. Of course, the transition process to the new form of data representation *can neither be attempted nor proceed in any historically familiar way*.

Before outlining in Sect. 5 the new formalism, in which the result of ‘measurement’ is not a number, let us name its form of representation **structural** (~ informational) **representation**. Here “structural” implies that *each* member s_i of the representation set (see Fig. 1.1) is not the familiar *point in some space*—an *unstructured* entity—but one formed by *linked structured units* (called *“events”*, see Fig. 1.5 in Sect. 5) that jointly encapsulate the object’s *formative* history, event by event.

Specifically, considering a constantly evolving nature of the Universe, I propose to interpret the “structure” of a concrete object o_j (Fig. 1.1) as its *“formative scheme”*, i.e. the informational ‘scheme’ of the object’s formation process, either in Nature itself or as perceived by an agent. In our case, the *“formative history/structure”* would be comprised of the interconnected *formative events*. (Such unit-event, with incoming and outgoing connections to other events, is the key to the *new* informational agenda; it usually serves as the *blueprint for its spatial counterpart*—the spatial event that one observes.) Clearly, *any* object in Nature, including the Universe itself, *is* the result of the ‘physical’ events involved in its formation, yet the *informational origin* (and structure) of the events have not been systematically considered. The concept of structured “event” is clarified in Sect. 5.

The main motivation for the idea of structural representation is related to a new hypothesis about the informational organization of the Universe (Sect. 7), and the relevant question here is this: Is there a **universal structuring law** in Nature? That is, Is there some kind of the universal *structure* that guides the development of all processes, including the formation of objects? If the answer is “yes”—and this is what I *postulate*—we must modify our scientific approach to what we consider an adequate “representational formalism”. In particular, we must additionally insist that the mapping we call “measurement” in Fig. 1 *preserves the postulated (object) structure*, whatever it might be.

Our answer to the above question suggests the *existence in Nature of the informational reality, including the corresponding structural representation*. In such case, the numeric representation cannot be considered as an adequate form of data representation, since it disregards, and hence cannot preserve, any reasonable (postulated) concept of object structure. In Section 7, I clarify the above hypothesis in terms of the just mentioned informational reality.

Our hypothesis has implications for an intelligent agent. Not having access to an object’s *complete* formative structure (as it exists in Nature), the agent, during the perceptual process, would have to construct the *subjective* representation s_i of an object o_j, *relying on its own arsenal of events*. In any case, the key is the underlying *concept of formative object history, or structure*, which is based on the just hypothesized *universal* structure, via interconnected structured events.

How do we approach the development of structural representation? The question has been raised repeatedly during the last fifty years, but it has never been approached in the way suggested above. My, unexpected, proposal is to return to *the single reference point* we have, the prehistoric, *temporal*, form of natural numbers and to construct their *event-based temporal generalization* (Figs. 1.4, 1.5 and Ch. 3). Why? There are three key intuitions. First, the basic idea captured by a natural number—simply counting the observed events—may (should?) contain the seed of a more general idea of structural representation. Second, outside the scope of *some* generalization of the concept of natural number, one risks completely losing touch with any, even generalized, form of the concept of "measurability", so indispensible in science. Lastly, but perhaps most importantly, the concept of a structured *event* is both the most universal and the most attractive representational currency conceivable (even an elementary particle is most naturally viewed as a sequence of events, Sect. 1.5).

Certainly, the new form of representation *must embody a previously inaccessible view of objects*, in particular, objects as evolving entities: if the structural representation does not capture a completely new to the present formal apparatus of science side of reality, its purported value would be illusory. As we will see, such generalization is possible and will be outlined in Section 5. In fact, this book was motivated by the implications drawn from such structural representational formalism.

Next, several general remarks about a structural representation are in order. For historical reasons, the numeric representation, as the sole form of scientific representation, has never been challenged and hence cannot be considered as superior to other *possible* forms of data representation. Obviously, not any choice of the representation set is acceptable. To be adopted in science, a structural representation must, first, be *universally applicable*; second, be *superior to the numeric form in terms of the information it provides about the actual* objects, ensuring, in particular, the existence of the 'two-way connection' between any object and the *class* of similarly structured objects to which it belongs (e.g., between the *representation* of a cat and that of the class of cats, Sects. 4, 6; throughout, I associate with "class" a more universal sense); and third, lead to a *more transparent, i.e. more directly interpretable, formal apparatus*. Naturally, if adopted, there will be a transitional period, when the two forms of representation will coexist. However, if the structural representation is a direct generalization of numeric, as is the case with the proposed representation, the issue of the coexistence of the two forms of representation should not be quite as critical or controversial.

We should expect the new formalism to address the needs of *all* sciences much better than its predecessor. The candidate for such formalism outlined here promises not only that; it clarifies the nature of information processing in general and induction in particular, including the nature of classes (of objects) in the Universe. It also clarifies the nature of time, as well as the nature of "emergence". As always, only time will tell what the deeper relations between the two formalisms are.

So the development of the structural representation was motivated by the incorporation of structure *directly at the level of data representation, rather than seeking some "structure" indirectly, via spatial (numeric), including geometric and algebraic, mathematical structures,* as has been the case in the accepted scientific enterprise. The critical point is this: if indeed, there exists in Nature the structural (informational) reality, the numeric approach cannot recover this structure, since such structure would have already been lost *at the level of data representation itself*.

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

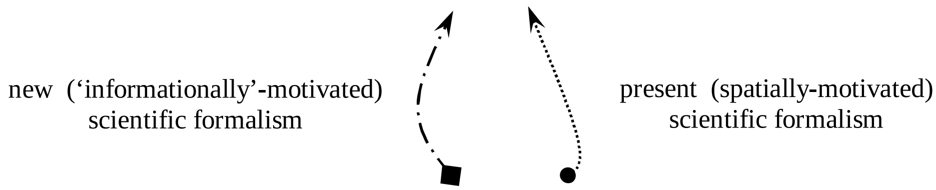


Figure 1.2: Our scientific ‘train’ is moving in one direction, and it cannot be redirected midway in an entirely different scientific direction, simply because the design of the ‘rails’ for the latter is based on a non-numeric form of data representation. When will they meet?

barley—numbers are not well suited for *representing objects or processes*, for which purposes we eventually started to use them 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 car and a tree have the same mass, this provides very little *information* about the two objects. Besides, if in a year, a mature tree grew—or in a billion years a mature galaxy evolved—their masses change but their *basic* structure may not have changed largely, and we then are 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: if the object representation should have the capability similar to that which biological evolution has endowed *all organisms*, then 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 chosen representational formalism. If so, we are facing the *main* scientific revolution that will be associated with the transition from the quantitative (numeric) to the qualitative (structural) description of Nature.

On an optimistic note, in general, we may have to face only a few, if any, such scientific upheavals: each new representational formalism should bring us much closer to the structure of actual processes in Nature. In fact, if the two hypotheses detailing the universal structuring law (Sect. 7) will be corroborated, we may need to undergo *just one* such great transition, since the proposed structural representation might already be a ‘mirror’ copy of the *actual* informational representation in Nature!

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

Developing their theories, the fathers of the Scientific Revolution relied on the then-emerging *historically unprecedented*, complete mind-matter split, in which “matter” became an *independent* and immutable entity subject to one change only—motion[6] (see Chs. 6, 7). Of course, as suggested above, *the mathematical basis available to them was not suitable at all for modeling the combined mind-matter reality* (not that such undertaking could have been productively considered at the time).

From a much longer historical perspective, this fateful mind-matter split was the most radical when considering the extent of the separation. The split, partly influenced by the then-dominant clockwork technology, was mainly motivated by the Christian worldview: the *transcendent* Mind, the Creator, not unlike a clockmaker, designed and produced all of Nature; and, since our minds originated directly from the Mind and are of *non-spatial nature* (mark that point), they are also not part of *the ‘material’ Nature*, which is based on *the mechanistic* principles. Yet decisive, for the *present* state of science, became the following *two implicit working assumptions*. First, since there is nothing ‘scientific’ one can say about the mental (as part of the divine), the scientific study of Nature can proceed by excluding the mental—today, read *informational*—from it. Second, the material or, as then interpreted, *spatially extended* Universe can be adequately modeled relying on the traditional mathematical considerations. The emerged (motion-based, Chs. 5, 7) orientation of science excluded any “informational” considerations and has resulted in what we call now *the* scientific view of Nature.

Thus, following the Scientific Revolution, all the ‘mental’—equivalently, *the informational*—had been ‘legitimately’ and completely *eliminated from the scientific picture*, and, today, no vague appeals to mind in quantum mechanics and the familiar efforts by neuroscientists and artificial intelligence researchers can change the situation. Why cannot this state of affairs be ‘corrected’ within the present scientific paradigm? Very briefly, on the one hand, the founders of modern science assumed (correctly) that the mind is of *non-spatial* nature and therefore had to be excluded from the scientific agenda. On the other hand, and more importantly, they (and the Greeks before them) have laid *the foundations* of our science, i.e. of physics, astronomy, and hence of all sciences, around the *spatial* concept of motion *understood within the numeric formalism*. As I argue in this and other chapters (e.g., 7, 8), the proper modeling of the informational, or equivalently formative, processes in Nature *is simply impossible within the numeric, or equivalently spatial, formalism*. (Indeed, what can the *formalism* developed on the bases of the machinery for treating *spatial* object motion, the formalism that now forms the core of our science, offer to *information* processing?) If so, we are facing the great, “informational,” junction in the development of science, which is completely unexpected for almost all scientists, but ‘logically’ and historically is inevitable.

Once again, I will argue that, *on the formal (decisive for science) side*, the elimination of the mental from the scientific agenda has been sustained by *the intrinsic structure of the only known to us formalism*. So here is the main reason, previously not appreciated, for starting our scientific journey anew (Fig. 1.2): *the above elimination of the mind (of the informational) cannot be reversed within* the numeric paradigm, under which the *informational side of reality* is invisible. (According to the formalism outlined in the book, it is the latter side that is responsible for generating the spatial side.) Hence, consistent with the above universal structuring law, without a fundamentally new, structural, form of data representation, to bring the mind into a scientific view of the Universe is impossible.

Although such new beginning could not have been productively embarked upon until the second half of the last century, by now it is long overdue. Here are just several relevant observations. I draw your attention to the first two, which are extraordinarily perceptive and especially interesting because the two authors represent a half of *the leading pioneers of the modern view of the Scientific Revolution*.[7] The first observation is made in 1965 by the late prominent Russian-French historian and philosopher of science Alexandre Koyré, who actually 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 every day—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. [8]

The next, rather harsh but astonishingly prophetic, observation is made in 1932 by the late American philosopher and historian of science Edwin Burtt:

> 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.[9]

To soften this accusation, I should note that, for historical reasons (Ch. 4), the underlying cultural *trends* driving the Scientific Revolution—including those related to the recovery from the medieval scholasticism during the Renaissance—were in opposition to the epistemologically inspired directions of research (not that such research, at the time, could have been very productive).

The third observation is made in 1986 by the contemporary American philosopher Thomas Nagel and (I emphasize) is quite 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] [10]

Finally, on the general consequences of our scientific view, we have the following observation:

> The mechanists' science [eventually] 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] [11]

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

Of course, the elimination of the mind-matter split within the new formalism should not be achieved at the expense of the overall scientific picture. I have reasons to expect, and I discuss them in the book, 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 new 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. As I mentioned above, the numerical apparatus was originally introduced for accounting purposes only, but was later *recruited as a form of object representation*. Occasionally, I point out why the resulting excessive reliance on numbers decisively contributed to the super-quantification of our society and to the many dead-ends we are facing today. Even though I address the relevant issues only superficially, from the humanistic side, they might be the most important considerations in favor of the proposed 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 traditional role of science in 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, more or less, incremental, similar to the previous scientific transitions or, for the fist time, non-incremental?

Most scientists—for whom scientific models replaced spiritual ones—simply shut out the more painful possibility of the historically unparalleled, *non-incremental*, change. Another, more pragmatic, reason for this 'blind spot' in the minds of scientists is that such changes would result, to put it mildly, in the deflation of their professional education and experience.

I, of course, believe this conceptual transition to be more drastic than the humankind has ever experienced since the emergence of numbers and cities. I already mentioned the need for a radically new form of data representation and the elimination of the mind-matter split as two reasons. Some other, concomitant, reasons will be discussed in this and other chapters. My answer should not surprise you, since the elimination of the mind-matter split—or equivalently, bringing mind into the scientific picture—has, indeed, enormous consequences. In the last century, such answer have been anticipated by many leading scientists, including Schrödinger, Einstein, Heisenberg, and many philosophers, including such unlike thinkers as Bergson, Whitehead, Čapek. Here is what the late American philosopher Ivor Leclerc (who was not even aware of the above informational considerations) had to say about the present transitional period in 1986:

> … 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. … This [subsequent] rethinking will affect science no less deeply than it will philosophy itself. And the consequences for human life will be no less great than were those of the [Scientific Revolution]. … [In view of t]he profundity of the Aristotelian insights … [w]e need … to come back to this source, … particularly in respect of the fundamental issues and problems. [[6], p. 208]

To reinforce this point, I also quote a most perceptive philosopher of science of the second half of the last century, the late Czech–American philosopher Milič Čapek, who, in his main book,[12] analyzing the state of physics, summarized one of the features of the coming monumental restructuring of science. In particular, Čapek gave a brilliant analysis of human perception of music, presented just before the segment quoted next, emphasizing a *non-spatial*, structural, nature of auditory perception (see his quotation closer to the end of Sect. 5) and hinting that the same considerations should apply to a future new form of data representation in science. The book was written in the 1950s, so it was too early to take seriously informational considerations, but his insistence on the role of non-spatial "events" in the future scientific framework does suggest that he saw this framework as associated with the informational (non-spatial) representation in science:

> The present transformation of physics is far more radical than the famous "Copernican revolution" of the sixteenth century. … [The latter] transition from the closed world to the infinite universe was not excessively difficult for human imagination: the earth merely exchanged its position with that of the sun …. The effort of imagination [apart from the usual psychological prejudices] required for such steps was

> relatively small. This explains why they were anticipated by the Greeks—the heliocentric system by Aristarchus of Samos, the infinity of space by Archytas and the atomists. … [T]he new Newtonian view of the universe was as pictorial [i.e. spatial] as the old Aristotelian one; indeed, it was even more so. …
>
> Today we are in the midst [rather, at the threshold] of a far more radical transformation of our view of nature. The most revolutionary aspect of this transformation consists in the fact that the words "picture" and "view" loose entirely their etymological meaning. As the so-called primary [relied on by science] qualities of matter now join the secondary [subjective] qualities in their exit from the objective physical world, it is clear that the future [informational?] conception of matter ought to be devoid of *all* sensory [especially spatial] qualities, including even those which are subtly and implicitly present in seemingly abstract mathematical notions [since the latter evolved based on the spatial consideration]. [12]

I try to clarify the above two appraisals in this and other chapters. Incidentally, in connection with the above monumental challenges, I cannot help noting our present predicament: we live in the most paradoxical period in human history, when the gulf between our culture, including science, and the urgent tasks facing us is probably the greatest (see also the chapter's last paragraph).

Thinking of the above unprecedented restructuring of science, one has to keep in mind that a scientist, as the most highly trained professional, cannot reeducate her/himself midstream. For this reason, he/she can *always* find various justifications for continuing with the millennia-tested numeric machinery. 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 the present disharmony in science or the primitive state of information processing—are brave enough to be open to the possibility or even *necessity* of the above radical conceptual change.

So again, I suggest that we are fast approaching a qualitatively new scientific and cultural age; we are poised to shift from the numeric representation—which prevents us from entering the Information Age proper, including the creation of Artificial Intelligence—to the structural representation (and the associated structural measurement processes), which is the basis 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.

4. Original motivation for the development of the new formalism

The new representational formalism developed by us—its technical name is "*evolving transformations systems*" (**ETS**, the acronym used throughout this book)—was originally motivated by the problems of *pattern recognition*, *classification*, and *induction* (generalization). So far, these tasks have not been approached as aspects of a *single* phenomenon, as I intend to do. The next chapter is devoted to a brief history of this ubiquitous *informational* problem that has confronted philosophers and recently scientists for well over two millennia. Instead of inventing a new term, I will use "**inductive process**" as a *collective* name (with the meaning different from the conventional) for the above phenomenon, which I claim to be the key to understanding the nature not just of biological processes, but the *information* processes in the Universe as a whole. Indeed, first, there are reasons to suppose the existence of a common *core* in all biological information processing systems, including the common *form* of 'data' representation. And second, if so, in a *prebiological* Universe, without any (informational) '*template*,' the emergence of this core is *unthinkable*. Why? As we know, given a particular planet in the Universe, we know that all sensory systems on it, if such exist, independent of how they came to be on the planet, do evolve, but the fact of evolution cannot explain the *emergence* of the *core* of their information processing systems. Moreover, any non-trivial change in the *structure* of such a core would completely disrupt the very process of evolution, since the new processes would not be interfaceable with those guided by the old core. The same conclusion also follows logically and empirically from what we know today about *all* conceivable informational structures: their core cannot be changed without destroying their integrity. This includes the basic form of data representation, which also cannot be modified without wreaking total havoc: just imagine what would happen if the new data coming into a system would have an entirely different, 'unknown', format. These considerations plus the proposed universal structuring law suggest that the most reasonable and, actually, the most stimulating assumption is the existence of *a single basic, pre-biological*, information-processing paradigm in the Universe. A similar conclusion can be reached when trying to answer two *related* questions: Why is *all observable reality* composed of *classes* of similar objects instead of being a collection of dissimilar objects? and Why has the survival of each biological organism on earth been ensured by the presence of the informational mechanism for learning various *classes* of objects in its environment? Today's science (physics) cannot answer such questions: we do not know why all processes in the Universe have always resulted in classes of similar objects, e.g. classes of similarly structured galaxies, stones, trees, fishes, etc.

Moving on to the all-pervasive problem of induction, or pattern recognition, or classification, or as some put it "seeing one in many", let us approach it via the following question: How does one recognize, for instance, a previously unseen cat (or an exemplar of "love") *as such* after seeing several cats (or examples of "love")? In other words, *how do several previous encounters with cats*—technically called *"the training set of cats"*—translate *into a representation of the entire class of cats?* The last phrase "*a representation of the entire class of cats*" signifies that such encounters result in acquisition of some form of class 'description,' but one should not interpret the "description" in its usual meaning (see Sect. 6). Addressing the last question, note that it is appropriate not only for a mind, but, more generally, for any biological sensing system. As it turns out, science has not moved at all toward even understanding this deceptively familiar problem; and that is despite the many centuries of quite intensive attempts by the greatest philosophers and the more recent *sustained* scientific and commercial efforts by the tens of thousands of researchers and engineers at numerous universities and companies throughout the world. For example, you may not know that Google, Microsoft, and Amazon have a large and increasing number of researchers working on it. You will better understand why after the next chapter and Chapter 11. So what are the difficulties?

In the above example, the mind must have access to some representation of the "the class of cats," otherwise, we would not be able to recognize *successfully* previously unseen cats or *generate* them in our dreams. Then, *what is the nature of the representation* of "the class of cats"? Is it informational (non-spatial)? Is it related to some 'intrinsic' structure of a cat? What is the connection between representation of a particular cat and that of the class of cats? *If we deny the reality of any one of the two possible forms of class representation*—in Nature and in an agent—we would then be confronted by at least one of the two *futile scientific issues*: why biological species have always existed as classes, and why, *from the beginning of life*, *every* organism has survived by relying exclusively on the classification of objects in its environment (based on the learned representations of the classes).

Second, since the *class* of cats, i.e. the cat species, exists in Nature, do, for example, "the *class* of stars similar to our Sun" and "the *class* of hydrogen atoms" also exist? If they do exist, they are much older than the class of cats. Moreover, if classes actually exist in Nature, how is their *evolving* existence and integrity ‘maintained’? Is this maintenance of informational nature? A positive answer to this question would imply the existence of an informational, i.e. *non-spatial,* form of storage in Nature, unfamiliar to the today’s science.

The *informational* concept of **class** of ‘similar’ objects, historically quite controversial, is a central one in the book. In this, quite general and hence sketchy, section, I am using that concept appealing to your intuition (although see Sect. 6). So what does ‘bind’ all cats into a class? I suggest it is their *common generative origin*: the ‘generation’, or ‘construction’, of each cat is *guided* by a single generative (involving embryonic) *process*. That process evolves in tandem with the evolution of the class itself. The same should be true for *any* class. Then, the *form* of representation of a single cat in Nature (and in an agent) must somehow reflect that generative character of the class. Of course, an agent does not have direct access to all the relevant events Nature has, so there must be some minor differences between the two representations, but those, I claim, are not essential. This is mainly because the *underlying forms* of object and class representations *cannot* change, since, as I already alluded to at the end of the first paragraph in this section, in contrast to the evolution of the Nature’s ‘hardware’, e.g. a DNA or an eye, (spatial realty), the modification of these two (non-spatial) *informational structures* would disrupt the *basic structuring code* in the Universe. To better grasp the point, imagine that at some point in the evolution of the Universe, the informational form of object representation, e.g. of some emerging new atom, has changed in a nontrivial manner. Is this possible? No, it is not, since the formation of this atom depends on the previously formed classes of atoms and particles and hence on their (earlier) representations. In other words, the new formation process would not be able to rely on all the previously formed object and class representations.

Regarding the inductive process in an agent, it might be useful at least to mention now—although we will clarify them later—two main and closely related *mechanisms* of this process, where the second one relies on the first. One mechanism—the class representation, i.e. the (informational) generative mechanism that can generate the representation of any class member and only of them—is responsible for the formation and ‘maintenance of’ each of the already learned classes; and the other mechanism (the classification) is responsible for associating a previously not encountered object *either* with one of the learned classes or, otherwise, with the initiation of the reorganization of those classes, which may involve the formation of a new class.

Next, I draw your attention to the indispensible role of classes in our culture and thought. Consider any human language. Note that any of the *meanings of any word in a language*—e.g. boat, mother, to love—*is not intelligible outside the class connotation*. For example, for any person, the meaning of the verb “to love” is actually a ‘label’ of the class of all the encountered instances of “love”. I do not think that such central role of induction has been fully appreciated. The latter is related to the lack of scientific tools to come to grips with that ubiquitous process. In particular, it looks like 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*. But the main strategic role of induction in science is related not only to its central role in the human information processing system or to my claim that induction cannot be adequately addressed without a new, historically unfamiliar, non-numeric, form of data representation. Rather the principal role of induction in the future development of science appears to be as the pointer to the proposed *central role of classes* in the informational organization not only of the mind but of the Universe as a whole (Sect. 7).

Coming back to the unsuitability of human languages for dealing with classes and induction, note that this is not surprising: the brain's mechanism responsible for inductive processes is of perceptual origin, so the language mechanisms simply rely on it. Moreover, it is the reliance on a spoken language to address the inductive processes that has caused many misconceptions about induction. Another source of the misconceptions is related to the lack of understanding of the concept of class (mainly because such concept, as mentioned above, cannot be properly addressed within the present scientific paradigm). In particular, this is the situation when a particular set of objects does not have a common generative origin and hence no *structural* 'glue' binding them together but is being treated as class. 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 seen 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 extensive formal attempts to approach the concept of class can also be intuited: what do, for example, 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 address the concept of formative structure in the language of "space," ubiquitous in science. To repeat, *it is the inaccessibility of a satisfactory concept of class within spoken languages and within the numeric formalism that have been the main sources of misconceptions about induction.*

As to the role of induction in the human—or more generally, biological—information processing, together with such unlike thinkers as Aristotle, Bacon, Helmholtz, Poincare, Russell (the last is quoted next) (see Ch. 2), I believe this process *to be the best candidate for the core information process*:

> 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 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 [since in both cases we rely on induction].[13]

Briefly (see the second half of Ch.2), what is the situation with induction today? Our core science, physics, was built on the assumption, revolutionary at the time of its genesis, that "matter" is a "substance" *by itself* (Ch. 4)—i.e. *not subject* to any formative process—and hence subject to *one kind of change only, change of place in the space*. It is to this end the core of our formal apparatus was developed. Thus, as I argue throughout the book, since inductive processes cannot be modeled within such mathematical setting (for modeling spatial motion), one cannot proceed with the modeling of induction in the manner we have been accustomed until now. Computer science also has not addressed the issue of induction,[14] until in the last 10–20 years it was compelled to hire the relevant specialists in view of the rapidly growing applied role of induction. Besides philosophers, relatively recently, induction has been of some concern to engineers, statisticians, cognitive scientists, and a few other groups. I explain the lack of progress with induction by the fact that it has not been approached as a *deeply* new *'natural science'* problem, where classes of objects should be viewed as an *integral part* of Nature. Nevertheless, the unprecedented aspect of the situation is that to approach this problem accordingly is impossible without the development of *a fundamentally new kind of formal language* and then learning how to work with it. Again, while the numeric representations of objects and processes in our applied mathematics—and hence in physics—are spatial and point-based, it appears here we are faced with the radical need to replace the only known to us form of data representation (of geometric, or spatial, origin) with a universal *structural* form of representation (Figs. 1.5, 1.7, 1.8). Thus, I claim that to enter the Information Age proper, we are faced with the unprecedented need for an entirely new kind of formal scientific language, introduced next, *with which we have had no experience whatsoever*.

5. A glimpse of the proposed structural representation: The new formal language

During my professional work as a computer science professor doing research in the area of pattern recognition, or pattern classification (or machine learning, as one of its present more popular names), it had become clear to me—and not only to me, see the quotation by Vapnik and Chervonenkis at the end of Sect. 2.5—that something very basic to the integrity of the whole area has escaped the attention of researchers. Eventually, I realized that what has been missing is the most basic concept, *the concept of class* (of similar objects), the concept that lies at the very hart of the field. An obvious question suggests itself: how is it possible that the field concerned with *class*ification has not addressed its most basic concept? The answer may surprise you: this central concept has remained under the radar simply because the existing mathematical formalisms make it *formally* inaccessible, and hence in many ways 'invisible': an adequate concept of class simply cannot be introduced within the numeric setting. One should keep in mind that *the exact sciences* are always built around already *existing* formalisms. Most importantly, the basic limitations of the formalisms cannot be transcended without abandoning them for new formalisms. In our particular case, we are faced with the extraordinary, truly unprecedented scientific situation.

The unprecedented nature of the situation, as I already mentioned, is that to address the concept of class we need a new *representational* formalism embodying the idea of *structural* data representation. Indeed, as we discussed, anything we see in Nature has a particular structure and *all objects from the same class must have similar structure*, e.g. oak trees, tomatoes, diamonds, the stars similar to Sun (G-type main-sequence stars). But how do we address the concept of object structure? Trained as a mathematician, I was completely unprepared for the *possibility* that the present mathematics as a whole cannot offer any satisfactory answer to the question. Gradually, I realized that the very issue of representation and the issue of structural object representation have *never* arisen before in mathematics, and they cannot be addressed relying on the known mathematical structures: *all structures* in applied mathematics are built around the spatial, point-based, representation of physical reality and hence cannot support the sought generative object structure. Again, the need for *such* radical break with the known formalisms has *never* arisen before, but this is not that surprising, since we are dealing here with the informational shift. I should also add that without such kind of break the informational shift, possibly our last frontier, cannot open up much anticipated entirely new horizons in the development of humankind.

Guided by the intuition supplied by the process of temporal construction of natural numbers (Fig. 1.4), we opted for the formalism where—as Whitehead, Russell and others have suspected—each object in Nature *is viewed and represented as the temporal stream of interconnected events that participated in the object's formation* (Fig. 1.5), either actual formation in Nature or, in the case of an agent, the formation simulated the agent's perceptual system. Such streams of events may overlap, as do many processes in Nature.

I draw your attention to the relevance of the proposed event-based view of reality to our central exact science, physics. Observe that a key feature of the proposed representation, the *succession* of events, is *the only* characteristic of time that has survived the upheaval of general relativity. Moreover, in particle physics, ETS representation strongly suggests the need to end the very misleading naming tradition in physics ("particle"), since what we call "particle" is actually either a single event or a stream of events, as can be gleaned from Figure 1.3. In the figure, most conspicuous events are seen as *junctions* each *transforming* the pattern of flow of one or several processes. Moreover, such processes are actually comprised of sequences of less conspicuous events. Below, we postulate that *informational events* introduced next—the *prototypes* of the physical events—are also junctions in various *informational* flows. Formalizing this intuitive picture, we come to the basic idea of the proposed structural or informational representation (ETS).[15]

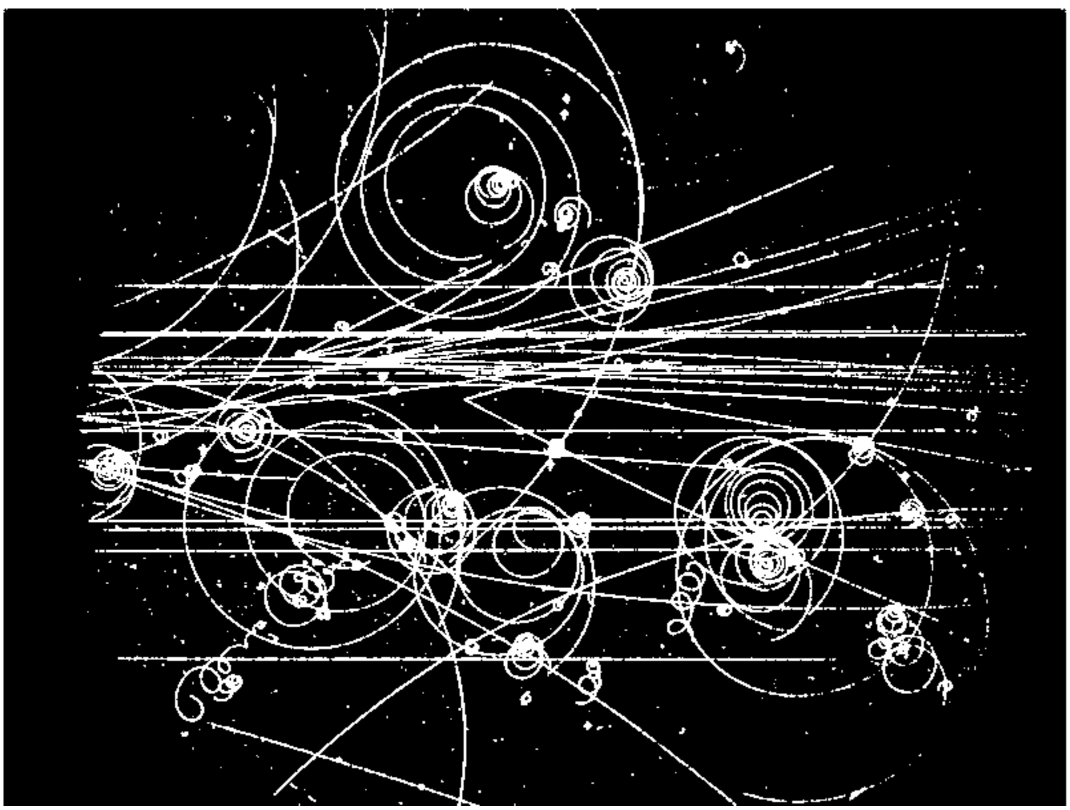


Figure 1.3: Each line, or track, in this bubble chamber photo of the particle beam, coming in from the left, is actually composed of a sequence of *events*, most of which we can hardly see, but as it is well known (see the quotations below), they are there.

http://cdsweb.cern.ch/record/842723/files/lhc-pho-1999-258.jpg

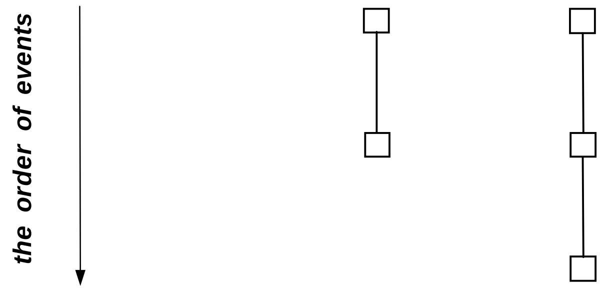


Figure 1.4: The *proper* representations of numbers 2 and 3 should be understood as *temporal* constructions involving the consecutive application of the *same event*, depicted as a square. (Actually, the number of processes in such event is not of essence, as long as all *events are identical and each new is attached only to the last one and in the same manner*.)

The informational, or structured, event—*a 'unit' of transformation*—is a *'junction' that transforms, in the way specific to the event, the flow of incoming information processes* (top "links" in an event in Fig. 1.5) into the outgoing ones (bottom links). Typically, such event is not a *numeric* transformation, since each "process" is non-numeric and may differ from other processes (in the event) *in kind*. Think of each process as an *abstraction of* an object's attribute. Think of an event as the *informational specification (blueprint) for its 'physical' counterpart*—when such exists—*that is supposed to transform some 'physical' entity* (Fig. 1.6). Among the countless examples of events, here are just several: various events in the expansion of the Universe, those in a chemical reaction, in the development of an embryo, in the production of a document, in a dream, or at an executive meeting.

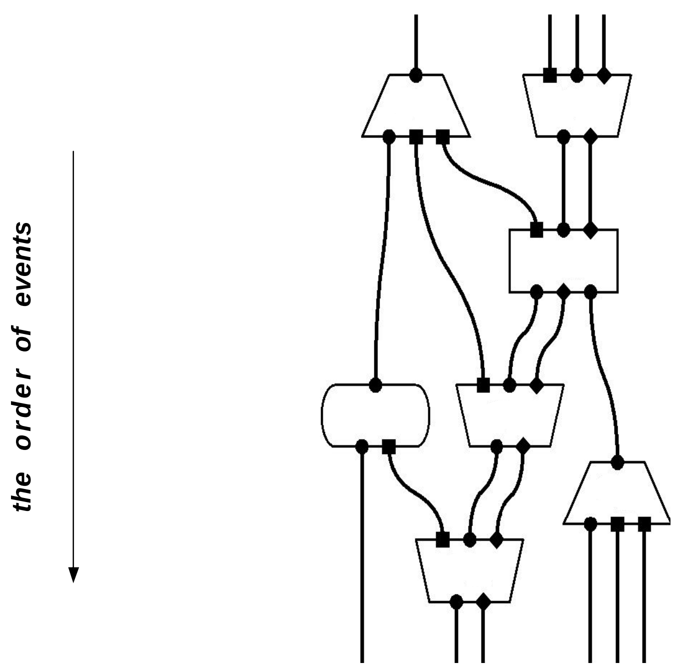


Figure 1.5: *Pictorial* depiction of a *small* **struct**. Each hollow shape stands for a particular type of **event,** of which there are four. Note *three kinds of links* (or "processes") coming in (top) and out (bottom) of an event; *each kind is designated by a small solid shape*, or alternatively by a fixed color. With respect to an object, think of the event as *specifying* its particular structural transformation (Fig. 1.6), and of a struct, as, *first, the blueprint for, and second, the record of the formative history* of the corresponding object.

As was mentioned, the concept of natural number provided some motivation for the development of ETS representation. In the axiomatics of natural numbers—Peano axioms (Ch. 3)—a natural number is viewed as a sequence of *identical events*, see Fig. 1.4; hence a number represents a *completely homogeneous* process, not involving *structurally different* events. So it is absolutely unreasonable to expect such homogeneous form of representation to be capable of capturing *non-homogeneous* processes, involving structurally different events and comprising practically all processes in the Universe (Figs. 1.3, 1.5). Indeed, if you consider any particular process, you will realize that its basic components are hardly ever all identical, independent of the nature of the process. At the same time, an object's mass, volume, or energy, for instance, convey hardly any *structural/formative* information about the corresponding object. To repeat: although we may use several units of measurement within a particular field, still each measurement device treats the corresponding events as indistinguishable. Our goal is to embrace the actual variety of events in Nature and to focus on their *structure and interrelations*. This is the basic idea behind the concept of *struct* (Fig. 1.5) outlined next.

But first, to contrast the two kinds of representation (review Fig. 1.1), 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*.

The new form of data representation, **struct** (Fig. 1.5), is a segment of a 'temporal stream' of interconnected informational events. Again, such events should be viewed *outside any spatial context and often play the role of blueprints for their spatial realization*. The latter are all around us: events that 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 give us an intuitive access to the connection between a struct and its spatial realization. In particular, think of a performed musical segment as a spatially realized 'musical struct' (originally in the composer's mind). In general, as in this example, the struct is both the informational *blueprint for*, and the *record of*, the structural evolution of the process/object it represents. Thus, a struct is a structural encapsulation of such *process*. (We shall see in the next section, there exists a stepwise procedure of struct *generation* closely linked with the concept of *class representation*.) As to Figure 1.5 and other *pictorial depictions of structs*, one should keep in mind that, as always, a pictorial, albeit meaningful, depiction is not the same thing as the abstract concept itself (defined formally in the first paper listed in [15]).

Note that an *event's structure* is identified by *the kind of transformation* such junction carries out (Fig. 1.6), i.e. by the *types* of the incoming and outgoing links-processes (explicit part) as well as the kind of transformation itself (implicit part). In fact, there may be two events with identical incoming and outgoing links that accomplish somewhat different transformations. Again, for an intuitive grasp of a struct and an event in it, one may rely on our perception correspondingly of a musical segment and a single note in it, keeping in mind that notes are *indivisible and qualitatively* differences entities. The object's structure—both in Nature and in the agent's 'mind'—is represented by the corresponding struct; hence the struct is the overall pattern of the interconnected events involved in the object's 'construction', either natural (in Nature) or perceived (by the agent). Such a pattern, or even the *structure* of a single event, cannot be *adequately* captured by *any* numeric representation. In that connection, I very briefly touch on the issue about which there exists a *widespread* misunderstanding even among scientists (I will come back to this briefly in the last paragraph of the section as well as later on). Take, for example, a *digital* recording, or more accurately *encoding*, of a short musical

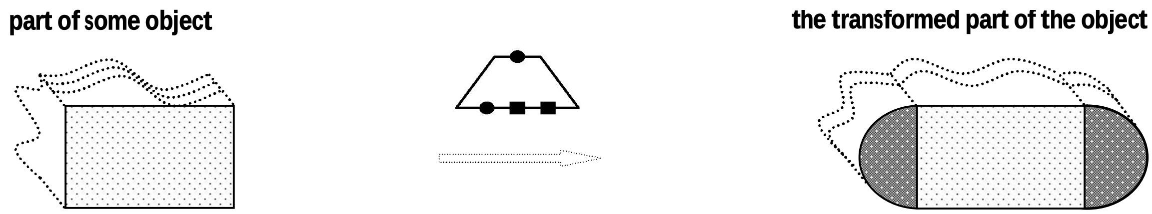


Figure 1.6: A stylized depiction of a hypothetical *instantiation* of one of the events from Fig. 1.5. In accordance with the *structure* of this event, shown in the middle, the instantiation is supposed to *transform* a particular 'part' of some object (on the left, corresponding to the input process, the top circle in the event) into the tripart (on the right), two parts of which are structurally identical and the third is structurally the same as the 'input' part. So the two solid circles in the event signify that the two, one input and one output, parts/processes are structurally identical. The *shapes* of the depicted object's parts have no relation to the small solid shapes in the event. (In general, the application of any other event from Fig. 1.5 either *reduces, preserves, or increases* the number of object's parts, depending on the *number* of its incoming and outgoing links.)

segment. This encoding has nothing to do with a *meaningful*—i.e. capturing the corresponding *informational structure (and hence the 'meaning')—representation* of the segment. In fact, our mind cannot meaningfully interpret such an encoding when faced with it *directly* in the digital form, and this is not due to the size of such an encoding. Recall that according to the above universal structuring law (Sect. 2), a true object representation must *adequately* reflect the object's formative structure. The illusion that this, *incidental*, digital encoding is a true representation is due to the existence of the retranslation of this encoding back into the sound form (but *actually* this retranslation is irrelevant).

Alluding to the proposed perpetual *existence in Nature* of informational representation (structs), I will use the term "struct's **instantiation**", or realization, to refer to the struct's *spatial or other 'physical'* realization based on the blueprint provided by it. Of course, in contrast to its instantiation, struct has no physical "size." Here is a helpful musical metaphor: think of the instantiation process as the 'execution' (from top to bottom) of the struct's 'notes'-events. Note that, relying on the concept of instantiation, the discovered in physics quantum, or pulsational, nature of matter and forces can be explained by the structure of the corresponding structs, where an elementary event is instantiated as a single pulsation. Not all structs are spatially instantiated, e.g., many 'mental' structs, including those involved in dreams. Observe that the structure of our own and other animals' behavior is directly explained by the structure of the instantiation process: the informational 'plan' of a behavior, i.e. the corresponding struct, *must* be formed, even if hastily and/or subconsciously, *before* its execution.

We will return to the "instantiation" in Sect. 8. Here are a few points in favor of existence *in Nature* of *some* kind of structural, i.e. non-spatial, representation. First, we do know about *some* kind of representation, as manifested in various nervous systems. Second, the 'data' accumulated in science does not offer a shred of evidence for the existence of *any* representation of *spatial* origin. See also the important view of von Neumann (his quotation in Sect. 1). Third, given the known from quantum mechanics "uncertainties", without a stable form of a process representation, the observed *regularity* of all processes in Nature and of their classes becomes quite puzzling to say the least.

Moreover, the proposed informational representation must be primordial, i.e. coexistent with the Universe itself (Sect. 4), and it should have been endowed with the capacity to specify and generate all the known spatial 'reality', hence my use of the term "blueprint".

For those who are familiar with various generalizations of the real numbers—i.e. complex numbers, quaternions, and octonions—note that, as is the case with natural numbers, the general struct has hardly anything to do with them as well. The decisive difference is the reliance on the structured events that capture, as was mentioned above, *an entirely new, formative, or structural, side of objects*.

The struct not only offers a non-spatially (informationally) motivated concept of representation, it also offers a *new conception of the discrete—the discrete as the formative structure*. The latter clarifies the quantum, or pulsational (as based on events), nature of physical reality, including the discreteness of electric charge, photons, energy, etc. and even of the motion itself. Indeed,

> 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 (γένεσιζ) and the annihilation (φυορά)—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] [16]

Those familiar with applied mathematical structures may have noticed that the (formal) structure of structs has no (direct) relation to any of the former. This observation, first, is a good sign, since structural—*understood via the formative structure*—representations should not have emerged within the spatial settings. Second, it brings up a deep issue of the relationship between structs and the conventional (spatial) representations, addressed by the instantiation. Incidentally, the *reluctantly* adopted in physics probabilistic interpretation of quantum mechanics is a clear testimony to the failure of the spatial representation as the principal one.

Support for the basic role of events in particle physics was repeatedly expressed by a prominent 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 … [events], so that observation only warrants us in regarding its existence as a succession of isolated events.[17]

Of course, Jeans is not alone in his view. Thus, for example, one of the fathers of quantum mechanics Erwin Schrödinger notes in one of his later books:

> If I observe a particle here and now, and observe a similar one a moment later at a place very near the former place, not only cannot I be sure whether it is 'the same', but this statement has no absolute [i.e. precise] meaning. This seems to be absurd. For we are used to thinking that at every moment between the two observations the first particle must have been *somewhere*, it must have followed a *path*, whether we know it or not. And similarly the second particle must have come from somewhere, it must have *been* somewhere at the moment of our first observation. So in principle it must be decided, or decidable, whether these two paths are the same or not—and thus whether it *is* the same particle. In other words we assume—following a habit of thought that applies to palpable objects—that we could have kept our particle under *continuous observation*, thereby ascertaining its identity.
>
> This habit of thought we must dismiss. *We must not admit the possibility of continuous observation*. Observations are to be regarded as discrete … events. Between them there are gaps which we cannot fill in. … That is why I said it is better to regard a particle not as a permanent entity but as an instantaneous

> event. Sometimes these events form chains that give the illusion of permanent beings—but only in particular circumstances and only for an extremely short period of time in every single case.[18]

Regarding these quotations, I should emphasize one important point that may have eluded their authors and which, at the same time, has been the main obstacle to our overcoming mentioned by Schrödinger "habit of thought". I mean the existing in science of the formal apparatus which has been gradually developed for over three millennia and which—including the geometry lessons in primary schools—has become practically compulsory spectacles for looking at Nature. Obviously, our present "habits of thought" cannot rely on any formal tools that would have helped us to see the basic reality of events. This state of affairs, although quite 'normal', *is* the major obstacle.

In philosophy, following the lead of A. N. Whitehead, Bertrand Russell—who in turn was followed by many others [19]—devoted a considerable part of his 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".[20] Later, concluding his *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." [21]

It is vital to recognize that *all, and not just "physical"*, processes are composed of events: events in particle physics, in chemical reactions, 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 perceptual and nervous systems when pursuing a deer, etc. Recall that the ETS universal structuring law hypothesis (Sect. 2) assumes *the struct* (or something like it), *as the underlying informational structure, to be pervasive in Nature*. In this connection, it is interesting to recall the remarkable view on perception of Henry Nelson Wieman, an American philosopher and theologian, expressed in 1943:

> True perception is achieved by discovering [and recording] the conditions under which certain kinds of perceptual events occur and thereby being able to infer [routinely] that certain past perceptual events and future possibilities are related to the present one according to a certain *structure of interrelatedness*. If I perceive a tree or table truly it is because I know that my present perceptual event is related to past perceptual events and possibilities in a certain definite way. …
>
> If this view of the matter be correct, a perceptual event taken by itself alone is never either true or false. Only propositions about how it is related to other perceptual events can be true or false. The perceptual event itself is a psycho-physical event. If I affirm that the perception happened when it did not, or that it did not when it, that affirmed proposition is false. *But the event itself simply happened. It could not be true or false. Only propositions about it can be.*
>
> …
>
> A perceptual event as here understood is never "in the mind" only. It is a happening that is physical since it includes light rays, sound waves, molecular and molar masses. It is physiological since living tissue, nervous and muscular reactions are involved. It is psychological and social … [when] signs and referents are included. If it is cognitive in the sense here defended, linguistic signs must be operative in the perceptual event, for without these no proposition can be affirmed or denied. The perceptual event is very complex. It includes everything which, if changed, would make a difference to the perceptual experience. This obviously makes it inclusive of vastly more than enters conscious awareness at the moment ….

… A perceived [recognized] object is always more than the present perceptual event. It is this event plus many others *all joined together in such a way as to make up a structure of relations*. *This structure pervading the interrelated events is the perceived object.* [My italics] [22]

A very important point—and possibly the main motivation for the development of ETS—is that the adoption of the structured event as the basis should *harmonize and unify* our scientific perception of reality with our sensory perception, since both would rely on the structured events (while, so far, science has relied on the numeric features). Indeed, the present profound disharmony (inconsistency?) was clearly stated by Erwin Schrödinger:

> … 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 [perceptual] qualities and therefore cannot account for the latter.[23] [See also the first epigraph for this chapter.]

Again, the possible achievement of the unification of the perceptual (qualitative) and scientific perspectives on the basis of ETS can hardly be overestimated.

Next, since the ETS representation has no previous analogues in science, to facilitate its initial intuitive grasp, two very simple *illustrative* examples are presented (another simple example, related to search engines, will be presented in Chapter 18). The first one is related to the events surrounding a head-on collision of two cars *as perceived by an external observer* (see Table 1.1 and Fig. 1.7). The second example (Table 1.2 and Fig. 1.8) is actually a *part* of the example from Section 2.9. In this, 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 attached to each other at the vertices. The exact spatial orientation (in 3-dimensional space) of a segment or triangle is not important. *To simplify the drawings of struts for this example, event links—which are mostly (qualitatively) distinct—are not shown as such*. For more details, refer to Section 2.9. An important point illustrated by the second example is that the proposed informational events *carry adequate information for their spatial instantiation*.

Moving on, observe that a struct evolves when the *appropriate* new events are (*permanently*) "attached" at the bottom of the struct, where by the "bottom of the struct" I mean the outgoing links of the struct's events that still remain free, i.e. unattached. So unlike the *visible* results of instantiations, the original (informational) events can never be 'undone', i.e. they cannot be removed from the struct, and the struct *constitutes the exact and permanent record* of the formative process. Also note that, sometimes, some of the *incoming* links in the newly attached event may happen to be connected to the outgoing free (unattached) links of some events that have occurred much earlier. (Of course, not all earlier events would have such free links.) 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, once again, as suspected by many—and the above quotations and references coming from a wide range of thinkers testify to this—the ETS representational formalism *postulates* the structured event to be the basic informational and representational unit. Such event is, in fact, a *universal (qualitative) 'unit' in the evolution of any process, and hence it becomes the primary 'unit of reality.'*

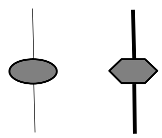
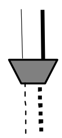
Events	An instantiation of the events
	two events, each, when instantiated, represents the movement of a particular car over some minimal distance; the incoming and outgoing links correspond to the particular car before and after that moment
	two-car head-on collision event: the incoming links correspond to the two cars just before the collision, while the outgoing links correspond to the two cars right after the collision

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.

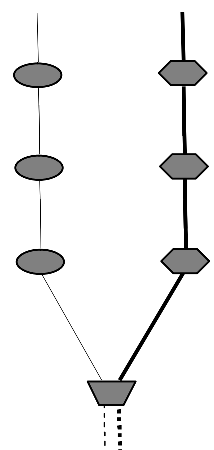


Figure 1.7: Pictorial depiction of the **struct** representing a qualitative, distant view of a two-car head-on collision and several moments preceding it.

The issues mentioned next will be addressed in Volume II (although see Parts III and IV of the first paper in [15]). The ETS formalism suggests that, first, the number of the most ‘elementary’ events in Nature is quite small, and second, there is be a bottom-up hierarchy of *representational stages, each with its own set of (macro) events* with the familiar *overall* structure, but each event at the next representational stage stands for a *compressed* struct segment from the previous stage. Due to such, *multistage*, structure of objects, their instantiation processes also exhibit a multistage structure (except these processes may possibly run in the top-down direction).

Also, the Big Bang scenario implies the existence of the Big struct—which represents the whole Universe and which has been growing ever since—subsuming all other, smaller, structs, including those corresponding to various fields known in physics.

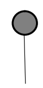
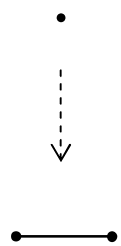
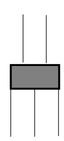
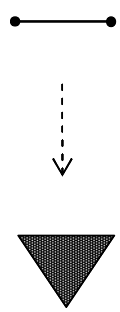
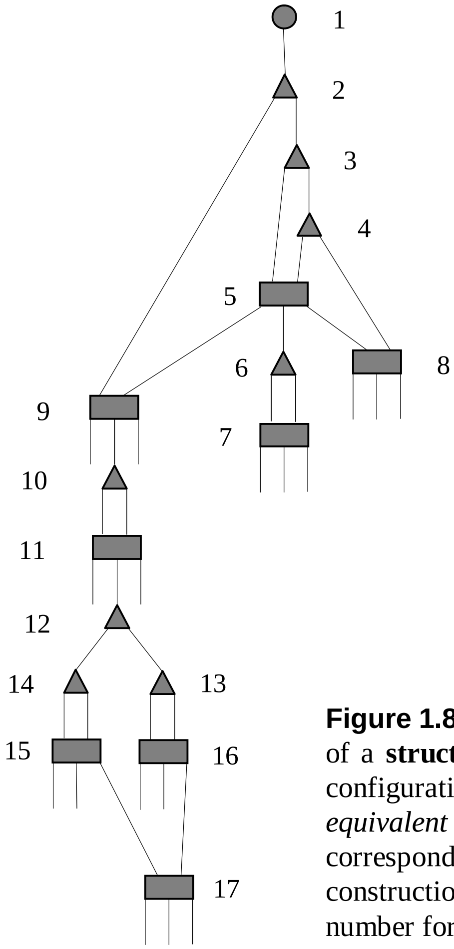
Events	A spatial instantiation of the events
	 the unique *initial* event: creation of a point; since this event initiates the generative process, it has no incoming links; I do not label this event (which would have been shown under the event)
 **P1**	 the expansion of a point into a segment; the right outgoing link in event P1 corresponds to the newly created point and the left one, to the old
 **P2**	 the expansion of a segment into the triangle *by fixing one of its ends and pivoting around it*; 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 1.2: Three events involved in the second example (left column: depicted geometrical shapes of the events have no spatial connotation). Since the top event can occur *only once*, at the very beginning, focus on the other two events (labeled P1 and P2). The incoming (input) links of each of those two events represent the processes acting on the previously instantiated *extreme* boundary points; 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 one of the above three events (P2 cannot be attached to the first event), the input process(es)/point(s) are *always* 'regenerated' (as the output ones) and are "open for business" again. To simplify the drawings, links of different *kinds* are not distinguished.



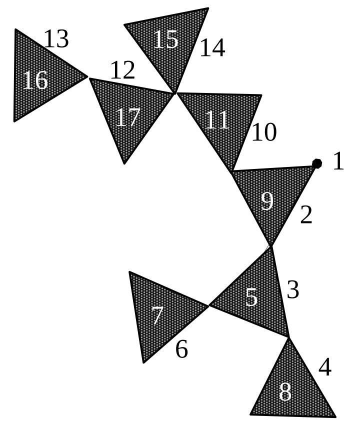


Figure 1.8: Second glance at the structural representation. **Left:** Pictorial depiction of a **struct** from the class *Triangles* (second example) whose members *represent* configurations composed *of triangles only*. Numbers indicate one of several *equivalent* orderings in which the events in this struct can occur. **Right:** The corresponding actual (instantiated) object with the same 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.

Regarding the *concrete* structure of the (hypothesized) basic physical events comprising the processes currently called "elementary particles", their discovery would be a highly non-traditional task before experimental physicists, 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 basic events can proceed *incrementally*, without changing *the underlying, event-based, form* of representation.

To repeat, Figures 1.4 and 1.5 depict two different versions of s_i from Figure 1.1, where the second one is the *temporal generalization* of the first and where a *single* event, out of which a natural number is built, is replaced by *several structurally different* events. Nevertheless, there is a *decisive difference* between the two versions. *While the natural number can be collapsed to a point on a line—obscuring its temporal origin—the struct cannot be reduced to numbers without loosing its structural, or relational, information* (including the event's interconnections and their *types*). Moreover, since events are responsible for 'constructing' the Universe, *in contrast to numbers and equations, their ontological status is indisputable (at least of the instantiated events)*.

The introduction of complex numbers, matrices, etc. as well as of the numerically 'inspired' (including various algebraic) structures in mathematics cannot substantially change the situation: there is no way to *recover* the qualitative structural information *missing right from the very beginning*, i.e. from the data representation itself.

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. The last point is so important that it bears reminding repeatedly. Our event-based representation captures an entirely different, structural, side of reality: in contrast to the numeric (homogeneous) representation, events are non-numeric entities and characterize the formative—temporal, structural, informational—side of objects, i.e. the way objects have come to be what they are. Note that ETS representation obviates the well-known *(artificial) constructions* in mathematics, e.g. vectors, matrices, which actually had to be introduced in order to compensate somehow for the basic homogeneous form of representation.

As will be discussed in Chapter 3, the common, collapsed, 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, 5 millennia ago. Furthermore, if the present attempt to capture the essence of structural representation is in the right direction, the shift from the 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 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.

Observe that, since the 'atoms' of ETS are distinct structured entities, the perennial *quantitative* question "how many?" in this case is not very informative and should 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.

In the following extended quotation by an outstanding philosopher of science Milič Čapek, I wish to draw your attention to his remarkable conclusions about our (auditory) perception of music that are intended to reveal some *general* features of all processes in the Universe. I inserted in the quotation, were appropriate, pointers to the ETS representation. I recommend reading the text at least twice: first, ignoring my insertions related to events and structs, and then, together with them.

> Let us consider a piece of music—for instance, a melody or, better, a polyphonic musical phrase. … At each particular moment [during the performance of this piece] a new tone is added to the previous ones; more accurately, each new moment is constituted [or actuated] by the addition of a new musical quality. But here we have to be on guard against the usual arithmetical connotation of the word "addition," and against the creeping spatial connotations which are associated with it. Arithmetic units remain distinct and qualitatively homogeneous [indistinguishable] no matter how they are grouped together; their grouping is purely external and does not effect their nature in any way. A "new" unit is added *ab externo* to other units without modifying them and without being modified by them. Although arithmetical addition … takes place, like any other mental operation, in time, its result can always be represented by a spatial symbolism, that is, as a juxtaposition of simultaneously existing units [see Fig. 1.4]. The relation of the arithmetical units to their sum total is the same as the relation of *the parts to the whole in space*.
>
> In the musical experience of melody or polyphony the situation is considerably different. The quality of a new tone [or generally, of a new event], in spite of its irreducible individuality, is tinged by the whole

> antecedent musical context [or the connections of the "new" event to some of the previous events, and this context] … , in turn, is retroactively changed by the emergence of a new musical quality. The individual tones are not … [unrelated] units of which the melody is additively built; neither is their individuality absorbed or dissolved in the undifferentiated unity of the musical whole.
>
> …
>
> … The musical structures [as are structs], in virtue of their essentially temporal nature, cannot be subdivided *ad infinitum* without being destroyed; they are, as Ehrenfels pointed out long ago,[24] *zeitliche Gestalten* whose duration is their existential minimum, which cannot be shortened without being destroyed. As Whitehead says, "a note of music [as is any event] is nothing at an instant, but … requires its whole period to manifest itself." [25] For this reason musical wholes—like physical processes—are not infinitely divisible ….
>
> …
>
> But in concrete temporal experience the emergence of novelty is possible, so to speak, only … [against] the contrasting background of its immediate past; in a similar way a new musical quality of the … [each next] tone acquire its individuality in contrast to, as well as in connection with, its antecedent musical context. There are no instantlike boundaries separating two successive moments of the experienced duration [i.e. of two events]; only when in our imagination we stretch a fictitious geometric line … [across the numeric] continuum of duration are we tempted to posit such boundaries, without realizing that they belong not to the temporal process itself, but only to its … [spatial] substitute.
>
> [Again, t]wo successive "specious presents" [i.e. events] are not separated by imaginary durationless instants [as if they are located in space], but *by their qualitative differences*. The term "separation" is misleading; it suggests separation in a spatial sense. We need to realize that the qualitative [= structural] differences of successive moments of duration are untranslatable into spatial imagery. To differ qualitatively and to be distinct in space are two different notions. Unless we do realize this, … [the events-based structural nature of reality] will remain to us forever obscure. [[12], pp. 371–74]

To reinforce the point about a "non-spatial" structure of our auditory (and not only) perception, one can also refer to the familiar example when in an Indian movie an actress singing in Indian brings viewers, who do not understand Indian, to tears (because they process the auditory input "qualitatively"). Regarding the above quotation, it exposes a revealing 'paradox': while, by definition, auditory perception receives its *input* via space, Čapek brilliantly observes that its *output* clearly exhibits non-spatial features, as it should. (Probably, a more direct sensing mechanism, as compared to vision, makes this perception process more 'transparent.') His observations tell us something important about the nature of information processing. I must admit that after reading and rereading the last two paragraphs in the quotation ten years ago, it dawn on me that the stream of primitives in a struct is not a spatial concept, and that it does not make any sense to look for "qualitative differences" (mentioned in the last paragraph) in the context of space, and hence the concept of struct should be viewed outside such context. It was not, then, that difficult to connect the structural concept of struct to the new, 'purely' informational, agenda and to equate the informational with the structural.

Next, I should at least mention (in this paragraph and the next one), mainly for the specialists, but still as plainly as possible, several key differences between the ETS and some of the popular in computer science non-numeric representations, such as strings, graphs, and propositions. The use of string representation was inspired by our language experience. Let us look at, for example, the use of this representation in computer vision. Consider a digitized handwritten small letter **a**, and consider one of its possible string encodings where various "structural" parts of its contour—when traced in a fixed (e.g. clockwise) direction—are designated by some symbols. For example, the bottom left arc ◟

can be designated by a Greek β (keep in mind that the above **a**, when digitized, looks *considerably* "magnified" so that between the bottom left and right arcs there might be several linear segments). As a result, the contour tracing algorithm would produce a string representation of **a** consisting of several Greek letters, including β. Now, going back to the middle of Section 2, we find *some necessary criteria* for a satisfactory structural representation. "To be adopted in science, a structural representation must, first, be *universally applicable*; second, be *superior to the numeric form in terms of the information it provides about the actual* objects, ensuring, in particular, the existence of the 'two-way connection' between any object and the class to which it belongs (e.g., between the *representation* of a cat and that of the class of cats, Sects. 4, 6); and third, lead to a *more transparent, i.e. more directly interpretable, formal apparatus*." Since for the purposes of the present discussion, in addition to the hypothesis of the universal structuring law (Sects. 2 and 7), I want to rely on these *three criteria*, let me slightly expand on each of them. *The first one* does not require any clarification, and it should be clear that the string representation does not satisfy this criterion: (linear) string cannot capture more complex, non-linear, and much more typical in Nature structural interrelations among the constituents (see also the last several figures). Even for our example of digitized letters, not all handwritten letters, e.g. Chinese characters, are amenable to this form of encoding. *The second criterion* draws attention to *the kind* and *quality* of information an object representation provides about the corresponding object. In other words, the relevant question is this: Compared to the conventional numeric representation, does the representation in question provides qualitatively "superior" (fuller) information about the corresponding object? The answer to this question, for the string representation, is only a "very partial yes": in the above example, the corresponding string hardly captures the character's formative history (i.e. the sequence of actual events when tracing a hand production of the character). As to *the third criterion*, the answer is also only a "partial yes".

Moving on to graphs, I should note right away that the modern *general* definition of a graph is so all-encompassing— allowing vertices and edges to be practically any entities—that our struct *can* be viewed as a particular, though very unusual, form of a *directed graph*, with vertices as events. Such interpretation of a directed graph is not typical to say the least, especially *considering the formative role of the events in the corresponding object's construction*. A much more typical usage of graph representation, for example in computer vision, is based on various *spatial* (!) interpretations of graphs, where vertices are some objects, or object parts, in the image and the edges reflect the adjacency relations between them. So under all popular applied interpretations of graphs, the above criteria do not speak in favour of graph representation. Moving on to a propositional representation, I note that, as language-based, it is not *directly* linked to the actual (physical) events in Nature, which is the main scientific argument against it. Also, all propositional operations—e.g. negation, disjunction, conjunction—can be realized by the corresponding ETS events. Concluding this 'technical' aside, in addition to the basic argument against *all* popular "structural" representations that they are artificial (as not event-based), the other argument is twofold. In light of our hypothesis of the universal structuring law, none of them can be a model of the actual structural representation in Nature; at the same time, none of them reveals any *fundamentally* new scientific information about the objects they represent. The latter, of course, implies that, scientifically, such representations are not essential.

(Following a common technical habit, one might be tempted, to try to *encode* numerically ETS structs, which completely misses the main point of the above universal structuring law. 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 supposed to be, overall, structurally correct models of the hypothesized informational events actually existing in Nature.* Put simply, there are profound, *unbridgeable* semantic and formal differences between numbers and structs.)

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

Here is a background question and the answer to it that are useful to keep in mind in this section. Why, despite its importance to many fields, the concept of class of similar objects has not been introduced within the known formal frameworks? And here is a short answer. Without exaggeration, *the only reasonable* concept of class proposed so far is that within the ETS formalism. This concept is defined via the concept of *class representation*, considered next, where the latter depends critically on the *non-spatial* (hence non-numeric) formative object structure discussed above.

The central informational concept of **class representation** [26], i.e. of class specification—without which the concept of class has so far remained obscure—is addressed in some detail in the next volume. In ETS, such specification is embodied in the **class generating system,** also addressed in that volume. This generating system is basically an *algorithm for constructing, or generating, all possible struct-members, and only them, for the present state of the class,* which explains the adjective "generating" in the name of this system. (Thus generated structs may then, when needed, be instantiated, Fig. 1.9; note that such kind of generativity is the key to the missing understanding of the nature of the class.) The algorithm itself is a *stepwise* specification for constructing each of those structs and only them. *Very briefly, with each step* is a*ssociated* the set of *structural constraints* specifying the kinds of struct segments *admissible* for the attachment at this step to the struct being constructed. 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, i.e. provided the appropriate connecting links match). In particular, the constraints may allow for the attachment of *some* struct segments that actually are supposed to participate in the construction of *other* developing structs *from other classes* in the 'immediate environment' of the struct under the consideration (Fig. 1.10). In other words, *some* other, active at the time, class generating systems (in the immediate environment) may be allowed to interact with the generating process in question.

We should keep in mind, first, that, together with any *spatial* object, both its representation (the struct) and its class representation also evolve: since each class member evolves, new class members emerge, or old ones expire, the class representation system changes to reflect that reality. This is accomplished via the *two-way informational 'link'*—with the instantiation being one of the two—*connecting every spatial object with its class representation (including the object's struct)*. And second, in a 'mature' Universe, for most classes, the class generating system is *capable* of 'producing' a large number of class members, which explains why the classes of macro-objects can be so large.

Incidentally, do not think of class representation as the class 'DNA' (see the second postulate in the next section). The ETS suggests that the actual DNA probably serves as a 'hardware' constituent only in the *instantiation* of the organism, since the class representation, as an informational concept, cannot be reduced to the hardware alone. Besides, DNA has a more individual connotation, i.e. it is presently associated with a concrete organism rather than with the entire class (e.g. species).

There are several *somewhat* closer (than DNA) scientific *metaphors*. The first one, coming from developmental biology, is that of the *morphogenetic, or organizing, field*. Such fields are presently

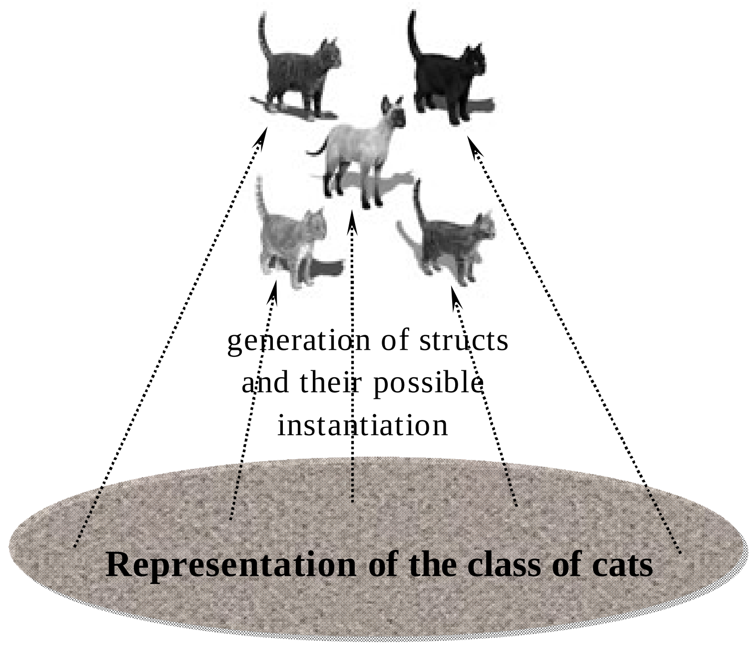


Figure 1.9: The role of class representation in the *generation* and *instantiation* of the class objects. Each arrow should not be interpreted as coming out of a particular 'location' but as indicating the dependence on the entire class representation.

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

hypothesized, and each of them is associated with the group of cells that, in *cooperation with the corresponding field*, bring about the specific morphological structure, e.g., an eye, a hart, or limbs. Hence such a field is supposed to guide the developmental process of each of the relevant cells (even

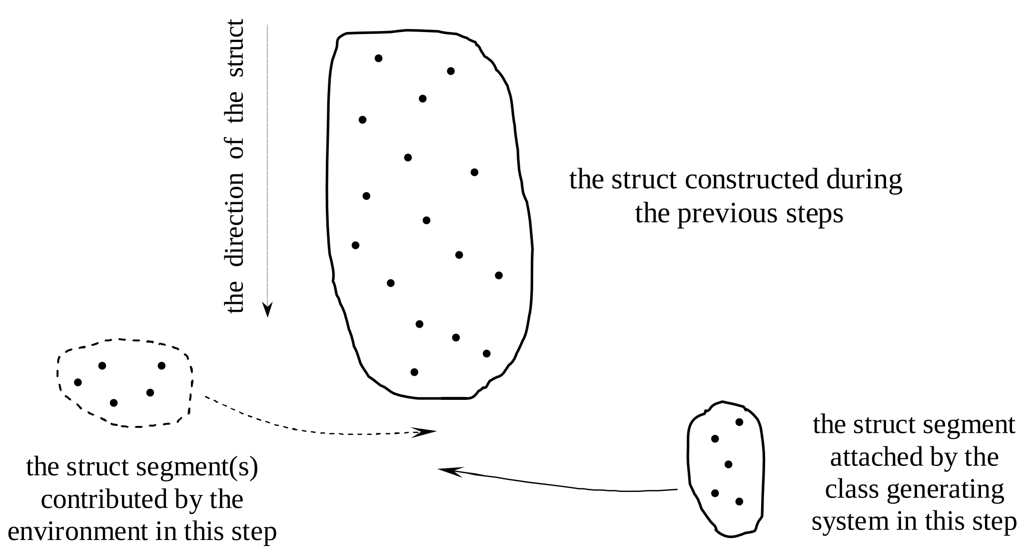


Figure 1.10: Schematic depiction of a generic step in the construction of a struct from some class, where, for simplicity, events are shown as points. During such step, the "environment" (i.e. some classes in the "environment" whose generating processes run alongside) *may* attach some struct segment(s) that is (are) *admissible according to this step's constraints*.

when the corresponding group of cells is transplanted to a different part of the embryo).[27] The second, more recent, possibly better known, and perhaps intuitively more transparent metaphor coming from the modern developments in theoretical physics is that of the *holographic Universe*. It suggests that a complete 'information' about, or specification of, any particular volume in the Universe—including Universe itself—*might* be stored immediately outside that volume, on its enveloping two-dimensional 'boundary' (e.g. gravitational horizon). In other words, any part of the Universe can be, *informationally*, viewed as a 'holographic image' of its enveloping surface.[28]

The important related questions such as "how a class and object representations might be 'stored' in Nature", "how the two-way relationship between a class and its particular member is actually 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 most likely this informational representation, as such, is not located in "space". (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 waiting for the detection of the graviton—the particle which mediates the gravity force—for a century, we should have enough wisdom not to expect quick answers to those, much more subtle, questions dealing with the nature of information.)

Another general remark is in order. Quite analogous to the situation in biology—phylogeny vs. ontogeny—it is important to distinguish between, on the one hand, a slow, very gradual process of object evolution, or formation, and on the other hand, the typically faster process of object *generation*. Object evolution is also associated with the evolution of the corresponding class of objects (generalization of phylogeny), while object generation process is a part of the *currently* existing class of objects (generalization of ontogeny). The similarities and the dissimilarities between those two processes will become more apparent in Chapters 14 and 15, 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. As will become clear later, the shorter–term process of *struct generation* relies on the *present* class representation and proceeds via a top-down event *differentiation*, from undifferentiated higher-stage events to the lower-stage events, i.e. in the direction somewhat opposite to that of the longer-term object/class evolution process.[29]

So in ETS, the class is delineated via the concept of (generative) class representation: no class representation—no concept of class. Such concept of class does not work in a numeric environment: points in a numeric space do not have any non-trivial generative structure. As a result, under the conventional mathematical setting, classes can only be *delineated* by the "decision surfaces" in the Euclidian space. Such surfaces "optimally" separate given finite "training sets" of points—i.e. those whose class identity is provided—from each other (see Section 2.6, including Fig. 2.1). Again, in a numeric setting, no generative, or extensional (i.e. explicitly *'producing'* the class elements)—as opposed to intensional (i.e. indirectly describing the class elements via some *'rules'*)—concept of class is possible. This explains the present attempts to do classification without the concept of class.

Thus—according to the proposed concept of class—if an object's 'formative' information is *not* reflected in its representation (as in the case of numeric representation), it becomes practically impossible, to *get from a small "training set" of objects (e.g. several cats) to the class representation*, where the latter depends critically on the formative information. I believe that the seemingly insurmountable difficulties encountered so far in addressing the problem of induction are simply the manifestations of this state of affairs. To repeat, the connection between the concepts of structural representation and that of class is decisive here: I suggest that if an object's representation does not incorporate, in some adequate form, the object's "formative" information, a satisfactory concept of class cannot be (and so far has not been) introduced for such data representation. These considerations should partly clarify my earlier observation about the strategic role of induction in the new development of science: only this problem brought the above representational issues to the fore.

As was already mentioned above, an object (and class) generativity, e.g. of a cat, *does not* imply that, for example, an agent's vision system relies on exactly the same object and class representation as Nature does: an agent's vision relies on the generativity that is supported by its own arsenal of events. But the important point is that the representation of cat in Nature is based on the *same* informational mechanism (class representation) as the cat's representation in an agent's vision system.

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 (that includes Microsoft and Google) *without* the benefits of the concept of class. Hence, again, *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 present computerized classification, despite the claims to the contrary, 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, via 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 formal 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 ETS formalism has to do with its *intrinsic* capability to accommodate, for the first time, a sensible, rich 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 struct carries *extensive formative, fundamentally* richer than the numeric, *information* about the object it represents. And second, according to the ETS definition of the class (the textbox at the beginning of the section), this richer information is directly relevant to the recovery of the corresponding class generating system: *all objects in a class have similar formative histories recorded in the corresponding structs*. For example, the structs of the several encountered cats should provide adequate information for the recovery by an agent of the "cat generating system". In other words, if an agent—based on its arsenal of events—stores the structs of, let's say, 20 cats, those should be sufficient to extract the appropriate struct segments and the 'rules' for putting them together (i.e. the constraints) for the initial version of the "cat generating system". (From our preliminary experience, this is a reasonable expectation; see the second and the third papers in [15]. Again, keep in mind that here a "cat's struct" refers to an *agent's representation of a cat*, which differs considerably from another, complete, struct representation of the same cat in Nature.) According to the universal structuring law from Section 1, detailed next, such *inductive learning process* is quite realistic, since all cats have similar formative structures, with a *common generative origin*. Note that everything we know from biology, especially from developmental biology, and linguistics points in that direction.

7. The universal structuring law: Informational organization of Nature

In this section, we come back to *our basic hypothesis of the universal structuring law* mentioned in Section 1. Before addressing it in greater detail, I should, first, draw your attention to the fact that—despite the increasing number of declarations by prominent physicists, biologists, chemists, and other scientists on the primacy of informational considerations—so far, science as a whole, has not considered at all the issue of *informational organization* of Nature. Moreover, I suggest it is this, previously uninvestigated, informational organization that might be responsible for the observed *structural regularity in Nature*. In other words, science has not addressed the question of structural regularity in Nature, namely why all objects/processes in the Universe fall into clearly delineated *classes of structurally similar objects/processes*, e.g. classes of galaxies, atoms, molecules, stones, organisms. So since *the present scientific knowledge tell us nothing about this structuring tendency* in the Universe, it is only natural that we must consider a new, truly informational approach to science.

I now restate the hypothesis of the universal structuring law (see Section 1) as the following **two main hypotheses, or postulates,** regarding the *informational structure and organization of Nature*. Historically, they represent the first attempt of this kind—i.e. explicitly addressing this informational structure—and they lie at the very foundation of the proposed structural formalism.

1. T*he 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, which, at the representational level, is captured by the ETS concept of struct (Fig. 1.5).

2. *The basic organization of Nature*. Evolving, interacting classes of informational processes form the primary organization of the Universe, where each class is specified by its class representation.

Note the key link between the informational and the structural (postulate 1). Also note that the second postulate is consistent with *the origin of the term 'information'*: when 'in-forming' someone we would like to 'transmit' the relevant 'Forms' (structures of the classes involved) in the sense of Plato and Aristotle. So the above view of Nature can be seen as a modern, informational, version of the Plato's and Aristotle's "Forms". 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 objects/processes interact, we would not see *qualitatively* stable outcomes, and hence we would see no regularity in Nature. The proposed informational explanation of the observed regularity in Nature is more satisfactory, or less artificial, compared to the conventional, law-based, scientific picture, where the equation-based laws appear out of nowhere, i.e. equations are not a *natural part* of the Universe (how do they appear and where are they stored?). Moreover, the reality of classes and their representations would be the main reason for *the prevalence of the constructive, or formative, processes in* nature,[30] *in contrast to destructive, or* *entropic*, *ones* (the second law of thermodynamics). I already mentioned above that such formative processes are not ‘visible’ within the conventional (numeric) formalisms.

As far as the underlying (tacit) assumptions of physics, and hence of all natural sciences, are concerned, the last point about the prevalence of the constructive, or informational, processes (also addressed in Chs. 8, 9) is impossible to overestimate. Indeed, our science—*without admitting any general structuring law in the Universe*—has evolved based on the *spatial* reductionist principle: to understand the nature of things, seek their (spatial) parts and assume they are more fundamental than the wholes, since, ‘obviously’, the whole is *just* the sum of its parts. The latter is ‘obvious’ only if no structuring (informational) law is assumed. Thus in physics the objects are reduced to the elementary particles, in chemistry, to atoms and electrons, in biology, to genes and proteins. As a result, for example, physicists—again, without admitting any general *formative* law—seek the *unified* theory at the point in time when *the objects we observe today did not exist* (the Big Bang). Is this reasonable? I do not think so. Looking at the same historically, from the 17^{th} century onward, our basic *applied* mathematical formalism (calculus), to a large extent, was built to the following *general* ‘specifications’ proposed and brilliantly implemented by the fathers of the Scientific Revolution. In contrast to the persisted up to that time Platonic-Aristotelian conception of the physical as a synthesis of “matter” and “form” (form = structure, or information), the radically new 17^{th}-century conception of the physical as “matter” *alone* was accepted, where matter is assumed to be *homogeneous* and *involving no process of change except locomotion*, i.e. motion in space. As a result, the “science of mechanics”, especially its formalism, became the core of physics, *around which all formal machinery of physics has grown*, and, *as any formal core*, it could not be changed later when all of the above “general specifications” proved to be wrong. To wrap up this (one-paragraph) account of the core of physics, it remains to recall something very important but, regrettably, by far not sufficiently appreciated: it is the now recognized structure of physics as fully based on scientific models, i.e. that it is the formal model dictates, or specifies, *all* the scientifically legitimate features of the reality it models. So we must accept that the intrinsic limitations of physics, *conditioned by its basic formalism* (with no structural view of the data), cannot be overcome by wishful thinking.

On the other hand, since at all observational levels the Universe consists of various *structured* entities, it is more productive to seek the key in the opposite direction, i.e. in understanding the ubiquitous *formative, or structuring, laws* of nature, which appear to be of informational 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 dependence on the *spatial* experience: we got used to the idea that things, especially those that we ourselves construct, can ‘easily’ be decomposed and *recomposed*. But in the real, *temporal*, realm, this principle is mainly not applicable, because *no flow of events can be reversed*. Even in the case when an object is constructed by us, its *precise* deconstruction is hardly possible.

It is misleading to think of the proposed informational organization as a collection of “fields”, referring to the physical use of the term, since a field is described by the (spatial) field equations.

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 primordial spatial event that followed (although the “Deed” should actually be understood as some macro-event).

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. The last two features are quite desirable: the explicit declaration of the informational structure of the Universe offers a new 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. (As always, 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 on the basis of which our science has been built. From this new 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 the Universe. Then, the wide chasm between the mind and matter disappears, since the mind relies on the same, class-based, informational structure that underlies the organization of "matter". I do not know of any other framework in which this chasm would be eliminated in such a natural way (see also Sect. 9).

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".[31] 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 present scientific perspective does: the Big Bang scenario implies the instantaneous appearance of the Universe (in the form of its mass/energy) together with the numeric laws (in the form of equations) that govern it.

Regrettably, computer science has been concerned only with various models of *computation* and not with the above or any other *"natural science" kind of approach* to information processing. As a result, computer science has substantially contributed to a pervasive *simplistic*, computational, view of information processing in the Universe, including the views in physics and biology. As we will discuss in Chapter 11, 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 logic [32], and this situation has played a decisive role in isolating computer science from the basic agenda of natural sciences. No wonder that in an (ineffective) 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 additionally 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 also 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".[33] This is, again, due to the focus of this new area on the computational and engineering aspects of quantum mechanics, which itself—due to its fundamental reliance on the "observer" and the related unresolved very basic issue of what constitute a measurement [34]—would benefit immensely from the development of the appropriate new information processing model; the role of the observer (i.e. of the mind), has been increasingly coming into prominence from the very beginning of this field. More importantly, as discussed in Chapter 8, although quantum mechanics, from the very beginning, has been faced with the *discreteness* of the underlying phenomena, still it *had* to rely on the *continuous* formalism simply due to the lack of any relevant (discrete) forms of data representation in our present mathematics.[35]

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 the *exact* instructions supplied by us; *they cannot be said to process any information* in the sense discussed above. 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. Such tendency becomes understandable if we keep in mind that, starting from the 16^{th} 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. So contrary to the widespread misunderstanding, present computers will have little to do with the future information processing "technologies".

Of course, such remote and unexpected negative consequence of the Scientific Revolution could *not* have been anticipated by its protagonists: as will become clear in Chapters 5, 6, and 11, information processing has nothing in common with the "matter", as it was understood by the heroes of this revolution. The above fundamental confusion, by itself, is another telling sign of the mentioned urgent need to address the present split between the physical and the mental (Sect. 3), *which is now seriously impeding our progress in all "information processing" fields, and hence in all sciences*.

There is, however, one unexpected but encouraging exception: the development of an important area of cognitive science, *linguistics*, points, at least to some extent, in a general information processing direction I am advocating. The founding father of modern linguistics, Noam Chomsky, since 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 $A \to B$, where A and B are some strings of abstract symbols. Such a 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: $S \to NV$, $N \to$ "the man", $V \to$ "danced" (S is for the start symbol, N is for a noun phrase, and V is for verb). We can now generate the sentence "the man danced" in three steps: $S \to NV \to$ "the man"$V \to$ "the man danced".[36]

Thus, the idea of grammatical generativity or generative structure, to which we will return in Chapter 12, 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, richer form of data representation. After all, compared to a struct, a string is just a linear *sequence of arbitrary* symbols, which carries very little 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, structural, form of representation, such as, for example, ETS.

The important lesson from the development of linguistics was formulated by Chomsky: since there are an *unlimited* number of grammatically correct sentences, they cannot all be memorized, hence *there exists cognitive mechanism capable of, and responsible for, generating an appropriate sentence immediately, as the need arises*. However, to account for such generative skill Chomsky is led to hypothesize the genetically innate "universal (i.e. one 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 the last reference): dreaming, movement control, mathematical skills, music composition, any 'design' skills, including those essential to the arts, and actually *all* thought processes. Compared to that unwieldy scenario, the proposed universal, simpler, and not specific to humans or even biological organisms informational mechanism of class representation offers immense advantages. So here too the advantages of the proposed by ETS *concept of object structure* and the corresponding generative mechanism become apparent when we think of the simplification and the unity they bring, compared to the (indefinite) multitude of the above unrelated, *somehow* evolutionary evolved and genetically embedded, mechanisms.

Regarding languages in general, above all, one should keep in mind that, since *the Universe has been formed by various events*, when communicating with the help of a language, of necessity, one attempts to point to the relevant events or collections of them, real or abstract. For example, "mother" points either to the birth event or to the events associated with the rearing of the child. Obviously, this point is useful to keep in mind when addressing language semantics: ETS representation of a sentence or a phrase seems to be a good candidate for a true semantic representation (see Ch. 16).

As to the topic of "consciousness" in the Universe and its relation to various classes (of objects), I do not discuss such issues simply because we do not 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 [29]).

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. Still, 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 structural view is on the right general track, then, again, *if we remain 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.*

Thus, I identify *information* processes in Nature with the *formative* ones, i.e. with those ubiquitous processes that are responsible for the maintenance of *all* classes of objects/processes, and hence of the objects/processes themselves. As will be discussed in Chapter 12, of course, I am not the first to suggest the basic role of classes in nature. But so far no science has undertaken the development of such view, which, I believe, is mainly due to the lack of the appropriate form of data representation. Also, in light of ETS, it should be clear why previous *numerous* declarations about a fundamentally *distinct nature* of "information" processes have remained scientifically inscrutable. Here are two examples of such declarations: the first, early, one by Norbert Wiener in "*Cybernetics*" (1961, 1st ed. 1948) and the second, recent, one by Seth Lloyd in "Programming the Universe" (2006).

> The mechanical brain does not secrete thought "as the liver does bile," as the earlier materialists claimed, nor does it put it out in the form of energy, as the muscle puts out its activity. *Information is information, not matter or energy.* No materialism which does not admit this can survive at the present day. [My italics, p. 132]

> [T]he primary actor in the physical history of the universe is *information*. Ultimately, information and energy play complementary roles in the universe: *Energy makes physical systems do things. Information tells them what to do.* [My italics except in the first sentence, p. 40]

In this connection, as discussed in this chapter, within the ETS formalism the above distinct nature of information processes becomes apparent, including the emerging view that the *road to the informational is paved with the new, structural, form of data representation*.

Finally, as outlined in Section 2 of the second paper in [33], I find it important to admit that the very *concept* of "information" is very ambiguous and scientifically unproductive. This does not preclude the possibility that some existing characterizations of an information *process* might still be interesting:

> 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. [37]

8. The precedence of the informational over the spatial according to ETS and its consequences

First, what is the present tendency in the interpretation of time by physicists? Based on the scheme (formalism) 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.[38] Such claims are not based on any fundamentally new discoveries and, from a formal point of view, are not that surprising. Indeed, *accepting the primacy of the spatial forms* of representation in mathematics (and hence in physics), time has been treated as an extra 'spatial' dimension, and all basic equations of physics are insensitive to the *direction* of time. Nevertheless, such 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, in addition to the well known quest by the late Ilya Prigogine to rehabilitate time in science [39], some other physicists have begun to realize "that we are far from having a good grasp of the concept of time" [40], 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." [41] 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 argue throughout this volume that the issue of time cannot be addressed adequately within the numeric (spatial) formalism. In other words, time cannot be understood in a spatial setting, as one or even several extra dimension, in which case we end up, for example, with such unnatural, but presently central, concept as *instantaneous state of a system*. As Whitehead 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. [[42], 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. [[42] , p. 152]

The best available in science treatment of time, in special relativity theory, via Minkowski 4-dimensional space-time, is still only a relatively small improvement on the classical treatment. Yet, this theory revealed the fundamental inadequacy of the classical treatment of time ([43], pp. 99–100):

> The very essence of special relativity theory is elimination of *absolute simultaneity*. There is no universal cosmic time, no *world-wide instant*, to use Eddington's term; in other words, no *Everywhere-Now* in the sense of an instantaneous cross section in the four-dimensional world history. The reason for [denying the simultaneity of events, as stated by Einstein himself in [44]] … is that … there is no such thing as a purely geometrical, instantaneous distance. As Whitehead observed as early as 1919 [in [45]] , "the spatial relations must stretch across time".

Of course, underlying all the issues we are discussing is the present conception of space as *separate* entity, which came gradually into science (and all our culture) during the 17th–19th centuries. Although I will address this deep issue (with the most profound consequences for science) later, in Chs. 5, 7, 8, here I should mention it at least in passing. Briefly, most of our present scientific difficulties might stem from the historically inevitable (mathematical-physical) conception of space as an *independent* ontological entity, i.e. *separately* "existing" in the form similar to that in which other familiar to us objects, e.g. planets, trees, and houses, exist. Such conception of space is, most likely, erroneous, as already Leibnitz and Kant had claimed [46] and as suggested by ETS.

I emphasize that we are discussing here the formal concept of space, as it exists in applied mathematics (hence in science) and not the perception of space, as our vision system delivers it to us.

What are, very briefly, the main differences between the two? The formal concept of space is of geometrical origin and cannot support the ubiquitous ongoing structural transformation of objects, which pervade the Universe (they were discussed in the first several sections of the chapter), while our vision system does allow us to observe, in our visual space, such structural transformations.

What is the idea of time emerging from the proposed formalism? According to ETS, time cannot at all be *adjoined* to space, since "time", if we insist on appealing to this term, is a *non-numeric entity* embedded in the stream of (informational) events. As a result, the conventional *numeric* time, not very unsimilar to money, emerges as an artificial entity. To see this, 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 *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. Hence, together with some contemporary physicists,[47] 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 the main idea of time emerging from ETS representation 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 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 emerges as inseparable from the irreversible stream of events*. In other words, time is 'dissolved' in this stream of events. There is no space involved, no spatial context: we are dealing with the purely informational flow of events, and consequently 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.

As mentioned above, when several consecutive 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, which, quite artificially, via the real numbers, led to the identification of time in physics with the extra dimension (a spatial concept).

Interestingly enough, ETS is consistent with the historically familiar "relational theory of time", going back to Lucretius (and hence even to Epicurus) and revived by Leibniz.[48] In contrast to Newton's "absolutist" theory of time (in which time is independence of space and its 'content'), this theory suggests that time is inseparable from the material "things". As mentioned above, from the ETS perspective, time is, indeed, inseparable from the structs and their (spatial) instantiations.

As to the overall relationship between space and time, on the philosophical side, we have the following amazing observation made already in 1920 by a prominent English philosopher Samuel Alexander: "Time is the mind of Space and Space [is] the body of Time." [49] This can easily be interpreted that the temporal (informational) is responsible for generating its "body" in "Space."

Next, what can be said about the concept of space in light of ETS? Since the structure of *the struct* is not related to the numeric forms of data representation, we are led to assume the precedence of this, ‘temporal’, or informational, structure over the spatial one, as has already been urged by a number of philosophers (Ch. 17). So we are left with the following scenario. Each spatial structure, including the space itself, should emerge based on the information contained in the corresponding struct (augmented, possibly, by some extra information). Here is, briefly, one, quite reasonable, possibility: the instantiation, or construction, of each spatial region is based on the information supplied by the corresponding struct (but not all structs relate spatial information) and is realized via the consecutive *instantiation of the struct’s events as spatial subregions*, where some links between the events specify the adjacency information between those subregions. In any case, this is one of the main roles of the structural representation—to provide information for the corresponding instantiation.

I should add that if, indeed, the informational “reality” guides the construction of the conventional, spatial, “reality”, the latter must have been organized accordingly, i.e. anything in the spatial realm, including biological organisms, must be equipped with the *built-in mechanisms that support the necessary two-way interaction*. An example of the evidence for such “mechanism” might be the neuronal structure (hardware) of the brain imitating the structure of structs.

The following implication of the special relativity theory opens the door to the above ETS hypothesis regarding a stepwise process of space instantiation (see also the last quotation):

> Because of the nonexistence of the universal cosmic “Now”, it is meaningless to treat the universe at large as an aggregate of *simultaneously* coexisting parts. [[43], p. 102]

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 the informational 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.

Significantly, the above precedence of the informational is consistent with the relatively recent proposals by the physicists working in quantum gravity (loop quantum gravity)—and even with the earlier proposals—also suggesting that the space might actually be generated by some more basic, discrete, structures.[50]

Given the *absolute* dominance of spatial mathematical models in science, it is interesting that the development of quantum mechanics—a central field in physics—for the first time in the history of physics, has pointed to the importance of non-spatial forms of representation. Indeed, first, the *need* to rely on the unexpected, probabilistic, interpretation of the wavefunction[51] is a clear indication that it was impossible to find a conventional, spatial, interpretation for this function. Second, the famed “indeterminacy principles” may turn out to be another evidence for the non-primacy of the spatial object representation. Third, the most interesting such evidence is the well documented “*quantum entanglement*” [52]: the experimentally established *instantaneous* ‘communication’ between several initially entangled particles (i.e. those generated by a single process), *independent of the distance that later separate them*. Since the upper speed limit is the speed of light, the latter implies the impossibility of such ‘communication’ *in space*, and hence we are justified in attributing it to the non-spatial, informational, realm (Fig. 1.11). Thus, it is quite possible that this experimental fact also supports discussed in Section 6 (non-spatial) informational concept of class representation, which may mediate such communication via the above mentioned two-way (instantaneous) link: any externally initiated interaction with one of the entangled particles transforms it, which in turn modifies its class representation, which then automatically, via the instantiations, transforms all particles in that class.

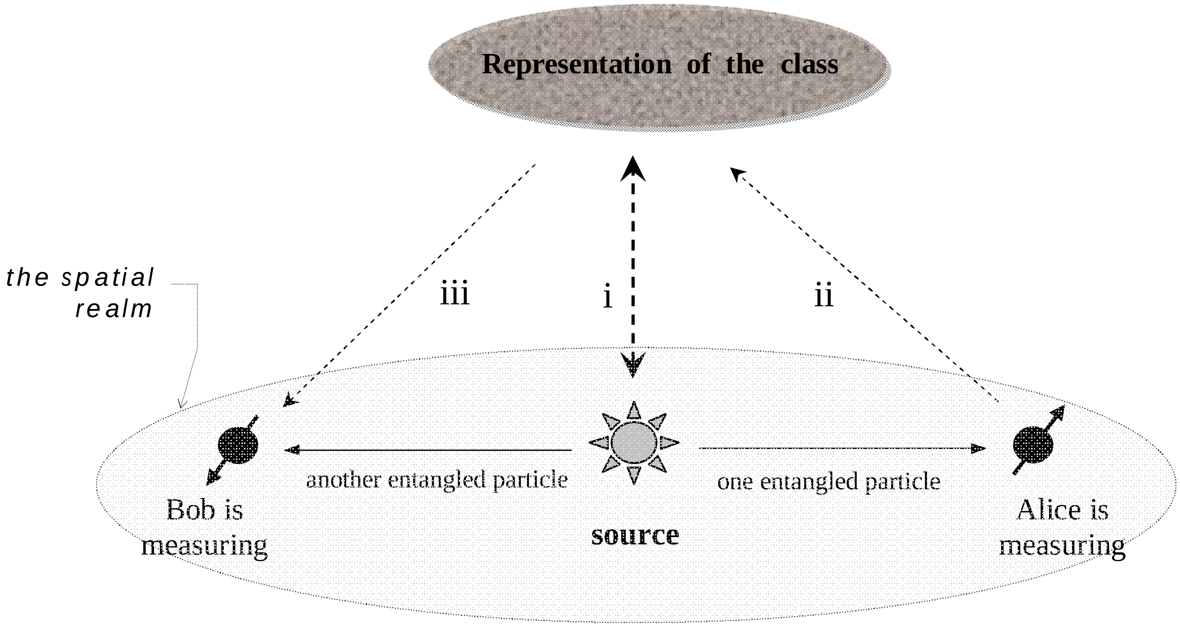


Figure 1.11: Possible, non-spatial, mechanism behind the quantum entanglement. The dashed arrows and the roman numbers represent events and their temporal order: (**i**) generation of the class "source" and emission of its particles (**ii**) Alice is interacting with the particle and this modifies (non-spatially) the class representation, which, in turn, modifies the class members so that (**iii**) Bob is now dealing with the particle from the modified class. (Here, the process of instantiation is supplemented by the corresponding 'feedback' loop.)

Regarding just-mentioned quantum entanglement, I draw your attention to two very important points. First, the corresponding well-known "entanglement" experiments (see, for example, [52]) *might* be interpreted as providing some *initial* evidence supporting the separation of the informational from the spatial as well as hinting at the underlying class-based informational organization. Second, the same experiments suggest that the process of assembling further experimental evidence confirming the latter separation may not be as infeasible as one might have originally supposed.

As to the *principal* modern progenitor of the overriding role of the temporal (compared with the spatial) in nature and in science, I must mention, above all, the name of an outstanding French philosopher Henri Bergson.

Concluding the section, it might be interesting to recall the view of Nature proposed by a great German philosopher Hegel supporting the feature of the ETS formalism discussed in this section: [53]

> [Hegel views] the idea of becoming, development or process … in its primary or fundamental form … [as a] logical [in the modern language, *informational*] becoming: a process, but *not a process in time or … in space [only]*, still less a change of mind or process of thought, but a process of the notion, a logical [informational] movement … . [My italics, p. 121]
>
> … the movement which pervades nature he [Hegel] takes, in the Platonic-Aristotelian manner, as a *translation of something more fundamental, namely, logical* [*informational*] *process, into terms of space and time*; … [hence] if the [classical] conception of nature as … spread out over space and time [only] is taken seriously, it leads to the conclusion that no natural thing or process ever has a home of its own either in space or in time [as non-localizable in space or time (due to the participation of the process in several

> physical fields)], and consequently the very idea of [a process as fully] existing in space or happening in time is an idea that contradicts itself. [My italics, p. 129]

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

As suggested above, ETS vindicates the evolving structural version of the Plato-Aristotle's view of reality as the instantiation of (informational) Forms. In this scenario—using the language of Plato's 'shadows-in-the-cave' metaphor—the *spatial* events we observe, considered previously as the primary reality, now become the 'shadows' of their informational (non-spatial) counterparts.

Returning to the issue of instantiation (Sect. 5), one might be tempted to point out that in the ETS formalism one kind of dualism, the mind-matter duality, is replaced with another, spatial-informational, kind. 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 integrate the mind* into scientific picture of the Universe, the original mind-matter split, as mentioned at the beginning of Section 3, has *completely removed the mind* from that picture (and left it in the dark). For the Information Age, the latter situation makes the mind-matter duality absolutely unacceptable. And second, in the case of ETS formalism, the use of "duality" to designate the spatial-informational relationship (if, indeed, it turns out to be correct) is not appropriate, since here, in contrast to the mind-matter duality, we are dealing not with a dualism but with a *monism*, in the form of a universal *precedence* of the temporal, or informational, representation over the spatial one, and hence with a clear causal relation between them. Appealing to the popular hardware-software distinction, this precedence may be interpreted as follows: 'hardware' (the spatial) is specified by 'software' (the informational). From these observations we can draw another important conclusion: given the fact that the mind-matter dualism (and the mind remaining in the dark) persisted from the beginning of modern science, we probably should not expect the two paths depicted in Figure 2 to meet in the *nearest* future. Moreover, given the present, informational, orientation of our economy and culture, instead of waiting until the two paths meet *before* undertaking serious work based on the structural representation, we should not hesitate shifting *now* our attention to the informational path.

Next, consider historically ubiquitous *opposition* between *the form* and *the process*, where our knowledge, *supposedly*, must be embodied in the permanent (geometric shapes, equations, etc.) and not in the changing. Already some Greek thinkers, including Parmenides and Plato, sought the refuge from the Heraclitian ubiquitous change, or process, in the permanence of the *forms*, including the laws expressed by (eternal) mathematical equations. Yet the ETS formalism suggests a natural resolution of this opposition: ex*ternally*, the class representation, as a primary informational entity, is the permanent (the old "form"), but *internally* it evolves together with the representations of its objects and the appearance of new classes.

On the formal side, as we discuss in Chapter 7, the present *basic* formal concept of space, mainly that of the *vector space*, does not allow one to model the conception of an *expanding* space necessitated by the Big Bang scenario. At he same time, the evolving in time ETS struct seems to capture the concept of a *structurally* evolving process quite naturally. In addition, the fundamental concept of "state" in physics, formally represented by a *point* in some vector space, also *does not* allow us to model this, *structurally* evolving, side of reality. In particular, the *spatially* motivated *transition* from one state to another, i.e. from one point to another in the spatial trajectory, does not and *cannot* capture the ubiquitous formative, or structural, side of evolution. That side, for example, is clearly exhibited not only by the expanding Universe itself but especially by the biological developmental processes. Incidentally, given what we know now about the complexity of the developmental processes, it seems impossible to even imagine any other relevant mechanism besides some new form of a purely informational one.[54] Taking into consideration the mentioned formal limitations of the present mathematical models, it is not difficult to see why *all* evolutionary considerations have had so far a very limited impact on the core of science as a whole. Not surprisingly, the only reason for the latter fact is that we simply do not have *adequate formal models* of the corresponding phenomena, i.e. we lack the 'right' formal language to explicate the phenomena.

Also on the formal side, we often hear and read today that "the focus of explanatory theories [in physics] moved away from their previous … purpose of postulating laws of motion to a rather more Platonic goal of explaining structure."[55] Such statements are mainly justified by the new, predominant role of group theory—and hence of the "symmetry" consideration—in the modern theories of physics. Since I will address this issue in Chapters 7 and 8, it suffices to mention here that the applications of group theory may have created the *illusion* of a "structural" approach to Nature. How can we talk seriously about extracting *substantive* structural information from the numeric, *non-structural*, form of data representation, i.e. from the data that, to begin with, hardly contains such information?

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 have encountered in "understanding" quantum mechanics[56] and in applying it to chemistry, biology, and neuroscience are a clear indication of the limits of our present scientific models. (I remind that the intrinsic limits of the present physics, and hence of its applications to the mentioned sciences, are set by the nature of the development of modern physics as based on the numerical models of *spatial motion of objects*, e.g. calculus. Indeed, this development proceeded *exactly* according to the overall plan outlined by Newton. "As he [Newton] wrote in the Preface to the first edition of the *Principia*: 'the whole burden of philosophy [read science] seems to consist in this—from the phenomena of motions to investigate the forces of nature, and then from these forces to demonstrate [all] the other phenomena.' "[57]) Yet in the face of the above difficulties, the reaction we observe today from many physicists and cosmologists is akin to the Ostrich Syndrome, proclaiming that it is the mathematical objects that are the only trusted reality.[58] In other words, the response to the difficulties is escape to the unprecedented fetishism of the present mathematics, as if its prestige has not already reached the historical peak. This is definitely not a productive attitude.

To repeat, the widely overlooked critical point here, discussed later in the book, is that all basic mathematical models physicists have relied on have *intrinsic* limitations resulting in a substantially reduced effectiveness when applied to the *structurally* evolving environments. Of course, structurally non-evolving environments capture reality during a relatively static, short stage of its development, and hence cannot address the evolving *formative* structure of real objects or processes. Yet, even for such classical topic as the process of object motion—which, interestingly enough, still remains conceptually unclarified[59]—the ETS formalism offers conceptually more sophisticated and, at the same time, more 'transparent' explanation. To simplify, what we observe is the sequence of the instantiated macro-events forming the object's "trajectory". The latter view, in particular, avoids the pitfalls hinted at by some of the famous Zeno's paradoxes that question the concept of continuity of motion.[60] Remarkably, it seems that two and a half millennia ago Zeno got it right: a truly "continuous" motion is impossible.

One more point regarding the existing mind-matter gulf. It is not difficult to see that the struct—as capable of carrying both kinds of information, *subjective* and *objective*—ensures the agreement of both *forms*, and it is this agreement that 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 general *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 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 "absolutist" concept of time: there is no *qualitative*, or structural, difference between the subjective and objective 'times' both relying on the corresponding events.

Moreover, the unity of the objective and subjective forms of representation brings out the unique and critical feature of the ETS: *the unity of its syntax and semantics*.[61] 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 concrete tree. 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 the 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, and their interrelations are intended to be the structural copy of their real-world counterparts. So if the ETS underlying hypothesis is correct, the formalism's syntax and semantics are obviously 'congruent'. Hence, as was mentioned above, ETS is a fundamentally new kind of formalism, which promises to radically change the nature and the role of representation in science.

This brings us back to the mentioned in Section 3 transitional period we are facing now in science. Again, if the two hypotheses of Section 7—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 the present-day physicists,[62] including the past statement by Heisenberg:

> The elementary particles in modern physics carry a mass. … Since mass and energy are, according to the theory of relativity, essentially the same concepts, we may say that all elementary particles consist of energy. This could be interpreted as defining energy as the primary substance of the world. It has indeed the essential property belonging to the term "substance', that it is conserved. [63]

What do I mean by "something much more radical" in the last paragraph? To understand this point it is sufficient to appreciate what we have to move *from*, and the following quotation by Einstein should help:

> 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.[64]

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 measurement practices, but its 'official inauguration' occurred during the Scientific Revolution. Yet, even then, prophetically enough, one of the revolution's main protagonists, Gottfried Wilhelm Leibnitz, was quite critical of *the primacy of space and objects in it*. After a careful analysis, Leibnitz concluded that an object, space, and an object's motion (among others) are not primary entities but are the manifestations of the underlying "plurality", i.e. they are manifestations of the "relations" among some hypothetical *non-spatial* and truly fundamental entities ("monads").[65] You can see some similarity with the ETS perspective.

An important example of the basic physical concept that should undergo a radical change is that of "elementary particle" as a material entity *continuously persisting in space*. The term "particle" itself is very misleading—these are not "particles" in any shape or form—and would need to be replaced by another less misleading term designating the spatial instantiation of struct (which is of 'pulsational' nature). Then, 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).

Given what we already know from quantum theory, my (ETS based) hypothesis about the nature of elementary "particles", although should be verified experimentally, looks quite reasonable.

> The neutron is a permanent constituent of atomic nuclei. It got its name from the fact that it is electrically neutral, i.e. has no electric charge. Yet it readily displays electromagnetic properties. This becomes understandable *only if we realize that the neutron can, for very short time intervals, transform itself into electrically charged virtual particles. This is simply the way a neutron exists.*
>
> *We conclude then that a single particle—a photon, an electron, or any other particle—continuously creates a host of other particles by virtue of its very existence, and that all these particles create and destroy each other in dizzying succession.* It is quite possible that what we call an "electron" is a

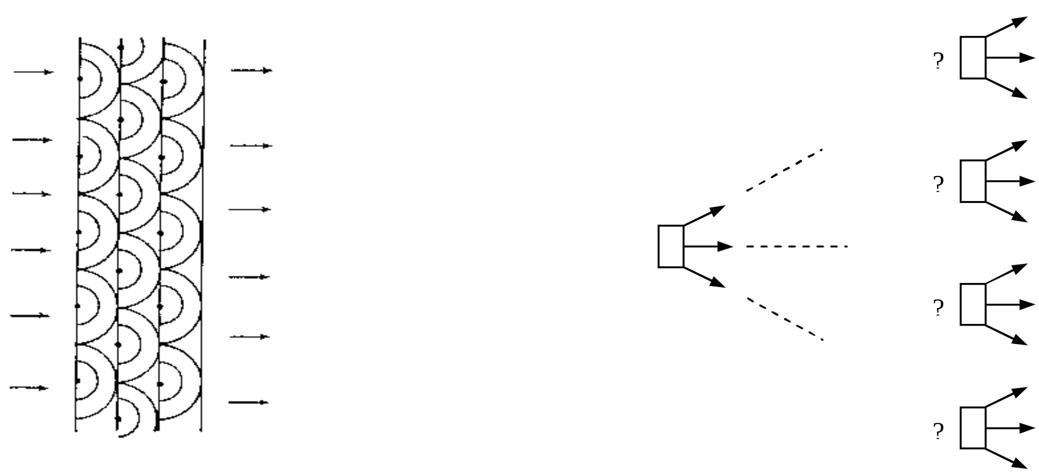


Figure 1.12: Left: The Huygens' view of light as a wave: each point on a wave front, in turn, acts as a new source. **Right:** A schematic (and more plausible) *ETS version* of the Huygens' view *for a single event*: an instantiated sequence of the depicted consecutive events accounts for both the observed wave and particle views of light propagation. To simplify the drawings, links of different *kinds* are not distinguished.

manifestation of some very complicated fast processes …. *These manifestations [or transformations] are* [structurally] *stable* and display measurable properties like charge or mass …. [My italics] [66]

At present, however, we have to live with the following quite confusing view:

The [electron] waves may equally well be interpreted as diagrammatic representations of our knowledge of the electrons concerned, for which reason they are sometimes described as "waves of knowledge'.

A full discussion of these results made it clear that matter could not be interpreted either as waves or as particles, or even as waves plus particles. Matter [and light] shows some properties which are inconsistent with its being waves, and some which are inconsistent with its being particles. It became generally agreed that it must be interpreted as something which is in some of its aspects reminds us of particles, and in others reminds us of waves, but for which no intelligible model or picture can be constructed. [67]

Regarding the general situation, it is quite telling that, as was documented by John Stachel,[68] Einstein, throughout his entire career, has been increasingly preoccupied with the possibility that the conventional, continuous, apparatus might be completely inadequate. For example, here are two paragraphs, each from a different 1954 letter, presenting Einstein's thoughts on this topic:

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. [[68], p. 286]

I should add that had the above well known experimental evidence supporting quantum entanglement (see the end of the previous section) been available to Einstein, it would have considerably strengthened his doubts, as it should, concerning the inadequacy of the conventional (continuous) formalism.

Not only the above (earlier) physicists but some modern physicists, e.g. Lee Smolin, also expressed their preference for the general direction associated with the proposed view of *physical* reality: [69]

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*. [My italics, pp. 210–11]

Moreover, the important remarks by one of the founders of quantum mechanics, Werner Heisenberg, are also consistent with the ETS fundamentally new conception of object structure:

[T]he mathematical forms, which could serve to describe the particle processes, *have probably not yet been developed* far enough by the mathematicians. … [I]n particle physics, too, there is the necessity of abandoning certain fundamental concepts of the earlier [and present] physics. Just as in relativity theory the old concept of simultaneity had to be sacrificed, and in quantum mechanics the notion of electron pathways, so in particle physics *the concept of division, or of "consisting of," has to be given up*. The history of physics in this century teaches us, that this *abandonment of earlier concepts is much harder than the adoption of new ones*. [My italics] [70]

Concluding the physics-related part of the section, it is appropriate to recall the opinion of the late dean of American theoretical physicists John Wheeler. This opinion, interestingly enough, is indirectly related to the famous dictum "*it* from *bit*" also coined by him:

> No theory of physics that deals only with physics [as it exists today] will ever explain physics. I believe that as we go on trying to understand the universe, we are at the same time trying to understand man. … Only as we recognize that tie will we be able to make headway into some of the most difficult issues that confront us. … Man, the start of the analysis, man the end of the analysis—because the physical world is in some deep sense tied to the human being. [My italics] [71]

Let us move on to another example of the coming radical change, in this case in our understanding of biological processes. In particular, I am referring to 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. Biochemist Franklin Harold also suggests that what has been really lacking in the substantive development of biology are the appropriate *formal tools* (à la 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] [72]

I cannot help mentioning that most biologists have accepted various 'promissory notes' by physicists for their face value and concentrated on molecular biology based on the conventional approach. 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, in particular, have duped many biotechnology investors (for which, at times, they latter literally pay high price[73]). I wrote "most biologists", since here, as always, there are some, unfortunately neglected, exceptions, which will be discussed later in this volume. In addition:

> In 2010, in a special series of articles in [a leading journal] *Nature* to celebrate the tenth anniversary of the completion of the first draft of the human genome, a common theme was *the "mismatch" between the sophistication of the data collection and understanding it*. In an article called "A reality check for personalized medicine," the authors observed, "*Never before has the gap between the quantity of information and our ability to interpret it been so great.*" [My italics] [74]

Among all fields, 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. Yet, in this field, and in advanced data processing in general (including the processing of various financial and surveillance data), in the last twenty years, the "gap" mentioned in the last sentence of the last quotation has widened probably by an order of magnitude. And the reasons for the lack of *real*, as opposed to a superficial, progress in these fields are similar to the above: the inability to appreciate the *fundamental* inadequacy of the existing formal tools to address information processing, for which purpose these tools were *never intended* in the first place.

As to mathematics, we often hear the statement that "mathematics is the science of patterns" [75] and that it helps us with advanced forms 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. 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 predict the structure of a future process based on its membership in the corresponding class of processes. And we will be able to do it relying on a much more general form of pattern prediction, the class representation, as well as on the richer variety of structured events themselves. Of course, as always, the time will show which of the two forms of pattern prediction is more powerful. Yet even now, we have some general clues about the comparative plausibility of the two models of reality. Among such clues mentioned in this chapter, I single out the following important consideration. Which "reality" is more probable: that with the informational class representations or the one with the mathematical equations (stored where)? Moreover, ask yourself: Can, for example, a concrete tree or a stone be actually "generated" by a set of equations? (Also recall the observations of John von Neumann quoted in Sect. 1.)

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 straightforward matter. Except for a stroke of genius, it is unreasonable to insist on seeing *immediately* the connection between the two approaches before a substantial development, with applications, of the proposed formalism takes place.

In the meantime, some of the *more urgent* needs we are faced with are the strategic decision as to the key role of induction (pattern recognition) in understanding the nature of information processing in the Universe, and if the answer is positive, the assignment to this field of the *scientific* status equivalent to that of physics. In light of what has been discussed in the chapter, one of the implications of such decision is that the attention accorded to any new *promising* (representational) formalism emerging within this field should be directly proportional to its ability to clarify the nature of induction and to how radically it differs from the classical formalisms.

Moving on to the implications outside science, in Section 3, 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 3, the fathers of the Scientific Revolution have already deliberately removed the mind and *anything 'mental'* (and hence informational) from the scientific picture. So the simple reason the Universe appears to be 'indifferent' to us—or, as the Nobel laureate physicist Steven Weinberg famously puts it, "pointless" [76]—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." [77])

Thus, I suggest that 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 oversimplified metaphors of biology ("natural selection", which Darwin borrowed from a Scottish fruit farmer [78]), and those of computer science ("computation", a mechanical process) have outlived their usefulness, and could not have done it for us anyway. In this respect, 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 appropriate, 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. Without assuming the existence of such *common* informational 'language', how else, in particular, would we be able to get to the basis of 'communication' between an organism and its environment? However, after being conditioned by many scientific periods of simplistic metaphors, we should have enough wisdom, including some patience (during these very impatient times), to develop this new 'language' and to allow for some transition time before reaping the full benefits of the new, informational, metaphor.

We should also come to our scientific senses and soberly reevaluate regularly 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: [79]

> 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 [e.g. the emergence of *all* laws, *all* matter, and *all* energy at the instant of the Big Bang]. 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 [especially those regarding the nature of the mind]. 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 history of science and the scientific common sense, including the respect for the phenomenon of mind, unequivocally suggest 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 scientific models. Indeed, the fathers of the Scientific Revolution—including Descartes, Newton, and Leibnitz—who 'designed' our main scientific road, could not had been that wrong when they placed the mind, as a non-spatial entity, far above that road. It is indicative of the situation that even in the last century, at least two (that I know of, and most likely more) of the *neuroscientists* Nobelists, Sir Charles Sherrington and Sir John Eccles, also viewed the mind in a dualistic manner. Second, to avoid the situation within artificial intelligence (AI), with a constant stream of unfulfilled promissory notes, one should insist that any new, encompassing the mind, model of "reality" must clarify *immediately*, at least to some extent, which *fundamental* side of "reality"—as it is presently understood on the basis of conventional models—has been missing. In other words, any new (most likely representational) formalism should account for the missing features of reality immediately and *directly, via its intrinsic structure*, rather than by an appeal to some promissory notes. Again, since so far we have been exposed to a *single*, numeric, representational formalism, we could not have learned about the decisive role of the chosen representational formalism itself, i.e. that it is the chosen form of data representation that determines the *overall* structure of the resulting scientific knowledge about Nature.

Regarding the second point just mentioned, during my professional work in AI, I was greatly surprised that the vast majority of workers in the field are not guided by the simple view expressed, among many others during the two millennia, by Thomas Nagel (the second epigraph to the chapter).

Moreover, this view must be instilled already in undergraduate students, not to mention the graduate students in the field. To take the opposing view, whether one likes it or not, is, in fact, to show a profound disrespect for and the misunderstanding of the phenomenon of mind. Why is it so imperative that, presently, science adopts the above 'Nagel's postulate'? Here is the main reason: relying on this, *temporary*, postulate, when evaluating one's own or someone else's new proposal in AI, we would be looking for a *fundamentally new* side of reality, *if any*, to which the proposed formalism is pointing. If such "new side" is not directly visible (which is true for the vast majority of proposals), the case for that proposal would be closed. Such postulate would not only, in some preliminary way, delineate AI field itself, it would also refocus our efforts on *more radical, rather than incremental,* approaches and, hence, would allow for an incomparably more efficient and productive way to proceed with the development of the field. So far, many tens of billions of dollars have been spent on "AI" and we do not have anything of a *true* AI to show for it.

Returning to the ETS formalism and considering its radical nature, it is especially pertinent to keep in mind the following important general observation by the late Russian philosopher of science, Georgij Ruzavin, regarding the role of experimental set up in science: [80]

> In contrast to [common sense,] … science, once it emerged from practice, as it develops, gradually begins to overtake practice by mastering new objects in the real world. It achieves this by … building their [object's' and phenomena's] theoretical models with the help of abstract and ideal objects. … The adequacy of such correspondence [in our case, between structs and the physical objects], or the validity of a theoretical model, is verified *not so much by the immediate practice as by means of the specifically developed for that purpose experimental method.* [My italics]

In other words, the appropriate experimental "methods", including structural measurement devices, must be developed anew, specifically for the ETS formalism, since they have to take into consideration the structure and the role of this representation as radically different from the only form of data representation we have relied on.

As far as the scientific investment in the ETS formalism is concerned, the risks are not as high as they may superficially appear, especially compared to the benefits *and* considering *the absence of any other* 'reasonable'—which in this case means sufficiently radical (as it *must* be)—suggestion regarding a fundamentally new direction in information processing.

One more important conceptual benefit of ETS is the resolution of the perennial philosophical doubt that "the real essence of substances is forever unknowable". Undoubtedly, the direction science has taken after the Scientific Revolution has contributed to the strength of this claim; and although some physicists, for some time, have been suggesting "that events and not particles constitute the true [and knowable] objective reality" [81], such suggestions could not have been implemented within the classical formalism (with its reliance on non-existing in Nature points, lines, and surfaces).

Lastly, here is a pragmatic argument in favor of the development of ETS (as the key to induction). In addition to the fact that all biological organisms are relying on induction and classification *each minute of their waking day*, there are, presently, many tens of thousands of people around the world—and their number is rapidly increasing—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 start the next chapter with an outline of the history of humanity's attempts to come to grips with that important process, the process of induction.

However, for those who will try *to understand the main reasons for the lack of a substantive progress* in that highly unconventional field, despite the massive investments in the last half a century, I suggest to keep in mind the following points. Quite naturally, by far, the main and obvious obstacle to the modeling of induction—*as based on structural, non-numeric, form of data representation*—comes from our thoroughly 'quantificational' both scientific and general (Western) cultures, whose emergence is discussed in Chapters 4. Moreover, as if this historically unprecedented challenge by itself is not sufficiently overwhelming, what has significantly aggravated the situation in the last 100–130 years is the need to face the challenge during the latest, 'spiritless,' stage of the Western culture. In particular, several decades ago, we have entered the period that can be characterized as *the age of incompetence* (manifested in a mounting inconsistency between an adequate and the actual professional performance, for which the general erosion of moral standards is mainly responsible). Thus, the misfortune of our present scientific (and social/political) predicament is considerably exacerbated by the rapidly growing an already *enormous gulf* between the reality of intellectually fading Western *culture*, 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. With the spread of "consumer culture" and the attendant emasculation of spiritual and moral values, this state of affairs has speeded up the ongoing *decline in the quality of all philosophical and aesthetic considerations in science and science education*, so indispensable in guiding the development of science in its latest, most radical, "informational" stage.

Notes

1. Tobias Dantzig, *Number: The Language of Science*, The Free Press, New York, 1954, p. 330.

2. Alfred W. Crosby, *The Measure of Reality: Quantification and Western Society, 1250–1600*, Cambridge University Press, 1997.

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 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].

5. For example, we have the following admission by the late leading physicists Richard Feynman:

> If, in some cataclysm, all of scientific knowledge were to be destroyed and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words? I believe it is the *atomic hypothesis* (or the atomic fact …) that *all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another*. In that one sentence … there is an *enormous* amount of information about the world, if just a little imagination and thinking are applied. [Richard P. Feynman, *Six Easy Pieces*, Addison-Wesley, 1994, p. 4.]

Note that the related (to "atomic") adjective "discrete" will be useful, for a number of reasons, to treat as an antonym of "continuous", as it is, indeed, often treated.

6. Ivor Leclerc, *The Philosophy of Nature*, The Catholic University of America Press, Washington, D.C., 1986.

7. H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry*, The University of Chicago Press, 1994, Section 2.3.

8. Alexandre Koyré, *Newtonian Studies*, The University of Chicago Press, 1968, pp. 23–24.

9. E. A. Burtt, *The Metaphysical Foundations of Modern Science*, Dover Publications, Mineola, New York, 2003, p. 320.

10. Thomas Nagel, *The View from Nowhere*, Oxford University Press, 1986, p. 52.

11. Ian Marshall and Danah Zohar, *Who's Afraid of Schrödinger's Cat? An A-to-Z Guide to All the New Science Ideas You need to Keep Up with the New Thinking*, William Morrow, New York, 1998, pp. xxiii–xxiv.

12. Milič Čapek, *The Philosophical Impact of Contemporary Physics*, Van Nostrand, Princeton, New Jersey, 1964, pp. 378–79. A more appropriate title of this book would have been "The Fundamental Inadequacy of Contemporary Physics".

13. Bertrand Russell, *Outline of Philosophy*, Unwin Paperbacks, London, 1986, p. 11.

14. Lev Goldfarb, Representation before computation, *Natural Computing*, Vol. 9, Num. 2, 2010, pp. 365–379, http://www.cs.unb.ca/~goldfarb/PAPERS/Natur_Comp.pdf .

15. The main, almost a hundred page long technical exposition is L. Goldfarb, D. Gay, O. Golubitsky, D. Korkin, and I. Scrimger, What is a structural representation? Proposal for an event-based representational formalism, Sixth Variation, *Tech. Report TR07-187, Faculty of Computer Science*, *University of New Brunswick*, 2008, http://www.cs.unb.ca/~goldfarb/ETSbook/ETS6.pdf .

Lev Goldfarb and Ian Scrimger, On ETS Representation of Human Movement, *Tech. Report TR07–184, Faculty of Computer Science, U.N.B.*, 2007, http://www.cs.unb.ca/~goldfarb/ETSbook/Walking.pdf .

Lev Goldfarb, Ian Scrimger, and B. Reuben Peter-Paul, ETS as a structural language for decision modeling and analysis: Planning, anticipation and monitoring, *Risk and Decision Analysis*, Vol. 1, 2009, pp. 85–101, http://tinyurl.com/cfw5nb.

Less technical expositions are:

Lev Goldfarb, Representation before computation, *Natural Computing*, Vol. 9, Num. 2, 2010, pp 365–379, http://www.cs.unb.ca/~goldfarb/PAPERS/Natur_Comp.pdf ,

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 ,

Lev Goldfarb, What is possible in physics depends on the chosen representational formalism, essay which won the forth prize in *the second FQXi essay contest "What Is Ultimately Possible in Physics"*, 2009, http://www.fqxi.org/community/essay/winners/2009.1#Goldfarb .

16. B. G. Kuznetsov, *Etudes on Einstein*, Nauka, Moscow, 1965, pp. 144–145 (my translation from Russian). Kuznetsov quotes Alexander of Aphrodisias who attributes the *origin* of such ideas to epicureans.

17. James Jeans, *The New Background of Science*, The University of Michigan Press, 1959, pp. 292–293.

18. E. Schrödinger, *Nature and the Greeks* and *Science and Humanism*, Cambridge University Press, 1996, pp. 131–132.

19. Events became a popular topic in modern philosophy and psychology, see for example, R. Casati, Events, *Stanford encyclopedia of philosophy*, 2006, http://plato.stanford.edu/entries/events , T. Shipley and J. Zacks, *Understanding Events*, Oxford University Press, 2008.

20. Bertrand Russell, *Human Knowledge: Its Scope and Limits*, Simon and Shuster, 1949, p. 250.

21. Bertrand Russell, *A History of Western Philosophy*, Unwin Paperbacks, 1985, p.786.

22. Henry Nelson Wieman, Perception and cognition, in Jack R. Sibley and Pete A. Y. Gunter (eds.), *Process Philosophy: Basic Writings*, University Press of America, Washington D. C., 1978, pp. 107–109.

23. E. Schrödinger, *What Is Life?* with *Mind and Matter* and *Autobiographical Sketches*, Cambridge University Press, 1992, p. 163.

24. C. Ehrenfels, Über Gestaltqualitàten, *Zeitschrift für Wissenschaftliche Philosophie*, Vol. XIV, 1890, pp.249–92.

25. A. N. Whitehead, *Science and the Modern World*, The Free Press, New York, 1967, p. 35.

26. See Part III of the first paper in note 15.

27. Werner A. Müller, *Developmental Biology*, Springer, 1997, pp. 183–84, and Scott F. Gilbert, *Developmental Biology*, 7th edition, Sinauer Associates, 2003, pp. 67–68: "One of the most interesting ideas to come from experimental embryology has been that of the morphogenetic field."

28. See for example, Paul Davies, Universe from bit, in Paul Davies and Henrik Gregersen (eds.), *Information and the Nature of Reality*, Cambridge University Press, 2010, pp. 76–79, or Wikipedia contributors, Holographic principle, *Wikipedia*, http://en.wikipedia.org/wiki/Holographic_principle.

29. 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 15, http://www.cs.unb.ca/~goldfarb/Physical_Instantiation.wmv .

30. See for example, R. G. Collingwood, *The Idea of Nature*, Oxford University Press, 1945 (or later editions), pp. 23–27, L. L. Whyte, *The Universe of Experience*, Harper & Row, 1974, Chapter III, and E. Schrödinger,

What Is Life?, Cambridge University Press, 1992, pp. 69–74, where the concept of negative entropy, or negentropy, was introduced.

31. See for example, John Barrow and Frank Tipler, *The Anthropic Cosmological Principle*, Oxford University Press, 1986 or Wikipedia contributors, Anthropic principle, *Wikipedia*, http://en.wikipedia.org/w/index.php?title=Anthropic_principle&oldid=436223231.

32. See my paper in Note 14.

33. See for example, Seth Lloyd, *Programming the Universe: A Quantum Computer Scientist Takes on the Cosmos*, Alfred A. Knopf, New York, 2006 and his suggestions for further reading on p. 219.

34. 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.

35. 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 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 .

36. See for example, Ray Jackendoff, *Patterns in the Mind*, Basic Books, 1994.

37. A. N. Arlychev, *Self-regulation, Activity, Consciousness*, Nauka, Saint Petersburg, 1992 (in Russian), p. 22 (my translation from Russian). The author attributes this view to several 1969 publications by the Soviet philosopher B. V. Ahlibininsky.

38. See for example, Julian Barbour, *The End of Time: The Next Revolution in Physics*, Oxford University Press, 1999 and Carlo Rovelli, Forget time, *FQXi essay contest on "The Nature of Time"*, 2008, http://www.fqxi.org/data/essay-contest-files/Rovelli_Time.pdf .

39. Ilya Prigogine and Isabelle Stengers, *Order out of Chaos: Man's New Dialogue with Nature*, Bantam Books, New York, 1984 or Ilya Prigogine, *The End of Certainty: Time, Chaos, and the New Laws of Nature*, The Free Press, New York, 1997.

40. Paul Davies, *About Time*, Simon & Shuster, New York, 2005, p. 9.

41. Lee Smolin, *The Trouble with Physics: The Rise of String Theory, the Fall of a Science, and What Comes Next*, Houghton Mifflin, Boston, 2006, p. 256.

42. A. N. Whitehead, *Modes of Thought*, The Free Press, New York, 1968, p. 152.

43. Milič Čapek, Do the new concepts of space and time require a new metaphysics?, in ed. Richard F. Kitchener, *The World View of Contemporary Physics*, State University of New York Press, Albany NY, 1988.

44. Albert Einstein, Autobiographical notes, in ed. P. A. Schilpp, *Albert Einstein, Philosopher-Scientist*, Open Court, Evanston, IL, 1951, p. 61.

45. A. N. Whitehead, *An Enquiry Concerning the Principles of Natural Knowledge*, Cambridge University Press, 1919, p. 6.

46. See, for example, Ivor Leclerc, *The Philosophy of Nature*, The Catholic University of America Press, Washington, D.C., 1986, Chs. 7–8.

47. Lee Smolin, *Time Reborn: From the Crisis in Physics to the Future of the Universe*, Houghton Mifflin Harcourt, Boston, 2013.

48. Milič Čapek, *The Philosophical Impact of Contemporary Physics*, Van Nostrand, Princeton, New Jersey, 1964, pp. 130–32.

49. Samuel Alexander, *Space, Time, and Deity*, Vol. 2, Dover Publications, New York, p. 38.

50. See for example, Chapter 15 (and the references) of Lee Smolin, *The Trouble with Physics: The Rise of String Theory, the Fall of a Science, and What Comes Next*, Houghton Mifflin, Boston, 2006. Among the earlier works I should mention that of Geoffrey Chew, which

> is based on the notion that physical reality at the microlevel is built from discrete quantum events: particle collisions, particle decays, and so on. The Cartesian macroreality of objects embedded in continuous space-time emerges from a collection of immensely large number of special ‘gentle quantum events. These gentle events involve the emission and absorption of photons by charged particles.
>
> The photon is a very special particle. It is massless and may carry arbitrary small amounts of energy; thus the disturbance of the particle, when it collides with the photon, may be arbitrary slight. Very large numbers of gentle photon events then create the illusion that the charged particle follows a continuous trajectory in space-time. [Fritjof Capra, The role of physics in the current change of paradigms, in ed. Richard F. Kitchener, *The World View of Contemporary Physics*, State University of New York Press, Albany NY, 1988, p. 153].

51. 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.

52. Wikipedia contributors, Quantum entanglement, *Wikipedia*,
https://en.wikipedia.org/wiki/Quantum_entanglement
See also George Musser, How quantum entanglement transcends space and time, FQXi blog article, Oct. 25, 2011, http://fqxi.org/community/forum/topic/994 .

53. R.G. Collingwood, *The Idea of Nature*, Oxford at the Clarendon Press, 1945.

54. Thus for example, already in the early 1980s, a leading developmental biologist and one of the major architects of molecular biology Nobelist Sydney Brenner summed up the view of his colleagues:

> At the beginning it was said that the answer to the understanding of development was going to come from knowledge of the molecular mechanisms of gene control. I doubt whether anyone believes that anymore. The molecular mechanisms look boringly simple, and they don’t tell us what we want to know. We have to try to discover the principles of organization, how lots of things are put together in the same place. I don’t think these principles will be embodied in a simple chemical device, as it is for the genetic code [R. Lewin, Why is development so illogical?, *Science* 224, 1984, p. 1327]

55. See for example, Roger G. Newton, *From Clockwork to Crapshoot: A History of Physics*, The Belknap Press of Harvard University Press, Cambridge, Massachusetts, 2007, p. 2.

56. The critical views of Einstein in this respect are well known, and he is not alone. Here is, for example, the opinion of one of the founders of quantum mechanics Erwin Schrödinger (see his *What is Life? and Other Scientific Essays*, Doubleday, Garden City, NY, 1956, pp. 161–62):

> A widely accepted [Bohr’s] school of thought maintains that an objective picture of reality—in any traditional meaning of that term—cannot exist at all. Only the optimists among us (and I consider myself one of them) *look upon this view as a philosophical extravagance born of despair in the face of a grave crisis. We hope that the fluctuations of concepts and opinions only indicates a violent process of transformation which in the end will lead to something better than the mess of formulas that today surrounds our subject.* [My italics]

Another, more recent, very informed opinion is that of John Bell, a prominent physicist who spent much of his career productively thinking about quantum mechanics: “It [quantum mechanics] carries in itself the seeds of its own destruction.” (J.S. Bell, *Speakable and Unspeakable in Quantum Mechanics*, Cambridge University Press, 1987, p. 27.)

57. Marie Boas Hall, Matter in seventeenth century science, in Ernan McMullin (ed.), *The Concept of Matter in Modern Philosophy*, University of Notre Dame Press, Notre Dame, Indiana, 1978, p. 95.

58. See for example, Max Tegmark, *Our Mathematical Universe: My Quest for the Ultimate Nature of Reality*, Knopf, 2014.

59. Joseph Mazur, *The Motion Paradox*, Dutton, New York, 2007.

60. Joseph Mazur, *The Motion Paradox*, Dutton, New York, 2007, Chs. 1, 7, 13.

61. Lev Goldfarb, Representational formalism in which syntax and semantics are congruent: Towards the resolution of Searle's Chinese Room challenge, *Proc. 30th Annual Conference of the Cognitive Science Society*, eds. B.C. Love, K. McRae, and V.M. Sloutsky, Cognitive Science Society, Austin, TX, U.S.A., 2008, pp. 1888–1893, http://www.cogsci.rpi.edu/CSJarchive/Proceedings/2008/pdfs/p1888.pdf

62. 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.

63. Werner Heisenberg, *Physics and Philosophy*, Harper and Row, New York, 1958, pp. 70–71.

64. Albert Einstein, *Ideas and Opinions*, Bonanza Books, New York, 1954, pp. 364–65.

65. Ivor Leclerc, *The Philosophy of Nature*, The Catholic University of America Press, Washington, D.C., 1986, esp. Chs. 2, 6, 9, 11.

66. Géza Szamosi, *The Twin Dimensions: Inventing Time & Space*, McGraw-Hill, 1986, p. 209.

67 James Jeans, *The Growth of Physical Science*, Fawcett Publications, Greenwich, Conn, U.S.A., 1967, p. 295.

68. John Stachel, The other Einstein: Einstein contra field theory, *Science in Context*, Vol. 6, Num. 1, 1993, pp. 275–290.

69. Lee Smolin, *Three Roads to Quantum Gravity*, Basic Books, 2001.

70. Werner Heisenberg *Encounters with Einstein: And Other Essays on People, Places, and Particles*, Princeton University Press, Princeton, New Jersey, 1983, pp. 54–55.

71. Quoted in Wolfgang Yourgrau and Allen D. Breck (eds.), *Cosmology, History, and Theology*, Plenum Press, New York, 1977, p. 351.

72. Franklin M. Harold, *The Way of the Cell: Molecules, Organisms and the Order of Life*, Oxford University Press, 2001, p. 252.

73. "Biotech's dismal bottom line: More than $40 billion in losses", *Wall Street Journal*, 2 May 2004.

74. Rupert Sheldrake, *Science Set Free*, Deepak Chopra Books (an imprint of the Crown Publishing Group, a division of Random House), New York, 2012, p. 169.

75. Keith Devlin, *Mathematics: The Science of Patterns*, Scientific American Library, W. H. Freeman, New York, 1996.

76. Steven Weinberg, *The first three minutes*, Basic Books, New York, 1977, p. 154.

77. N. David Mermin, What's wrong with this quantum world, *Physics Today*, Feb. 2004, pp. 10–11.

78. See for example, Sarah Knapton, Did Charles Darwin 'borrow' the theory of natural selection?, *The Telegraph*, 28 May 2014, http://www.telegraph.co.uk/science/science-news/10859281/Did-Charles-Darwin-borrow-the-theory-of-natural-selection.html .

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80. G. I. Ruzavin, *Philosophy of Science*, 2nd ed., UNITY, Moscow, 2005, pp. 6–7 (my translation from Russian).

81. James Jeans, *The New Background of Science*, The University of Michigan Press, 1959, p. 295. Also, see for example, Erwin Schrödinger, *Nature and the Greeks & Science and Humanism*, Cambridge University Press, 1966, pp. 121–22, esp. pp. 131–32, and the above quotes by Lee Smolin (note 67).

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 16^{th}–18^{th} 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 formal setting, this 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; in an informal setting, the adjective is quite ambiguous and I suggest to interpret it as an antonym of "continuous"; the proposed here radically new form of data representation is supposed to clarify the nature of "discreteness" as "structuredness"

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; throughout the book, the adjective "generative" when used with "mechanism", "system", etc. refers to an informational 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 $\psi\ (x,\ t)$ which is supposed to embody a complete description of the quantum state of a particle; in contrast to the classical physical description, $|\psi|^2$ 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 *generative* 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 'in-forming' 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 past events can be undone: the past can 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*.
- 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), possibly the greatest mind of all time. Indeed, as one of the most profound philosophers of the last century A. N. Whitehead pointed out, "if we are to accord to anyone the position of the greatest metaphysician, having regard to genius of insight, to general equipment in knowledge, and to the stimulus of his metaphysical ancestry, we must choose Aristotle." [1]

Although he does refer to Socrates as the practitioner of the method, it was Aristotle himself 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 some critical perspective, below I quote one of the most known in the last century antagonists of induction (and hence of Aristotle), Karl Popper.

First, Aristotle is the father of 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 scientistic [sic] sense and the theoretician of scientific proof and the authoritarian claims of Science. [2]

Most relevantly, in the *Prior Analytics*, *Posterior Analytics*, and *Topics*, Aristotle outlines his theory of *epistêmê* (knowledge; Plato separates *epistêmê* from *dóxa*, common belief or opinion). How did

Aristotle arrive at it? Let us follow Popper's, though oversimplified and quite critical, still suitable, description. The *main* oversimplification concerns the omission of the role of perception and perceptual knowledge in grounding propositional knowledge (see this section below).

> … [B]eing a clever man, and a good logician, he [Aristotle] finds that his assumption that there is demonstrable [inaccurate adjective, here and below] 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 … 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 [like], 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 from Chapter 1, titled "Introduction: Aristotle's invention of induction and the eclipse of Presocratic cosmology", in one of his last books.[3] In that short chapter, Popper states that "the main reason why I do not like Aristotle" is his suggestion that one can have *epistêmê*: "what to Plato is a scientific hypothesis becomes with Aristotle *epistêmê*, demonstrable [poor rendering of Greek] knowledge. And for most epistemologists of the West, it has remained so ever since." Plainly, this is a gross misinterpretation of Aristotle's *epistêmê*: the emphasis on the human capacity for well-grounded knowledge was very progressive, especially at that time. Also, in the same chapter, Popper repeatedly 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 unfair 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 his students. 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.

Continuing with 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 toward 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 1.6 (see also Figures 1.8, 1.9 and Sect. 2.9) and mainly addressed in the sequel to this volume. The denials of the existence of such nontrivial but central process as induction, most prominently by Popper himself (see Sect. 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!

What did Aristotle propose? *In contrast to modern logicians*—who practically ignore induction—the founder of logic realized that the knowledge expressed in propositions is completely divorced from the physical world and hence needs some grounding in the *actual* objects and processes. Moreover, once he realized that "the method by which even sense-perception implants the universal is inductive"[4], he proposed that we should also 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 thirty years ago[5], *before I was aware of the Aristotle's proposal,* I actually outlined a formal mechanism for realizing his proposal (which eventually grew into ETS):

> 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'.

Moving on to Aristotelian *Forms*[6], note that, originally, forms were conceived by Pythagoreans, and presumably by Pythagoras himself, as capturing the nature, or essence, of things. It is form in things that makes them to be what they are. The form, or structure, is supposed to shape the matter, whose function is precisely to take on various forms.[7] Of course, Aristotelian *Forms* are related to induction and to the structure of classes of objects (*modern* meaning is related to "informational structures"). Among various meanings of *Form* in his works, William D. Ross, a leading scholar of Aristotle, identifies the central ones as "the inner nature of a thing which is expressed in its definition, the plan of its structure [cf. our 'formative structure' in Ch. 1]".[8] Aristotle did try to improve on Plato's not evolving, transcendent *Forms*, but at that time it was absolutely impossible to deal constructively with the relevant concept of informational structure. Incidentally, sometimes one inaccurately attributes Greek *εἶδος* (*eidos*) or Latin *Form* exclusively to Aristotle, while the Greek *ἰδέα* (*idea*) to Plato, but 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 [part of] 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 [fully] resolved into actuality; hence Aristotle says that … *pure* actuality *contains no matter. Thus, anything situated somewhere in space is material, because it might be somewhere else and still remain [informationally] itself* … . [My italics, [7] , p. 92]

Incidentally, in ETS, the issue of potentiality vs. the reality is considerably clarified: it becomes the issue of the (non-spatial) informational class representation machinery vs. the informational-spatial instantiation machinery (see Sects. 1.5, 1.7).

Yet perhaps the most important point about the Aristotelian *Forms* is that they offer us another glimpse into his theory of knowledge (epistemology), which represents an absolutely remarkable anticipation of what is being proposed here. Indeed, how do I hear, or perceive, for example, the ringing of a bronze bell according to Aristotle?

> Now, the bronze of the bell, and the gases of the air, do not enter into my organism; but the rhythm of their vibrations does enter into it; and it is precisely this entrance of the rhythm into my head which is my hearing of the sound. But a rhythm is a Pythagorean or Platonic form; it is an immaterial thing, a type of structure, or in Aristotle's language a *λόγος* [logos ('formula' or 'definition')]. To hear a ringing bell, then, is to receive into one's own organism the *λόγος* of the ringing bell … ; and this, generalized, gives us Aristotle's definition of sensation. … Similarly with sight and the other senses. In every case there is a perceived object, which is a certain kind of matter possessing … a certain form: *to perceive that object is to reproduce the form in ourselves* while the matter remains outside ourselves [cf. the concept of class representation, Sect. 1.6]. Hence Aristotle's definition of sense as the reception of sensible form without its matter. [My italics, [7] , pp. 85–86]

In a sense, Aristotle's general view of matter as a body of an organism can be considered as a culmination of the long tradition of all ancient civilizations, including Greeks, who spontaneously approached nature as an organism. Yet the Scientific Revolution of the 17^{th} – 18^{th} centuries, with its sole emphasis on the spatial motion of material objects, and especially after the development of the corresponding formal apparatus, completely reversed this earlier general trend (Chs. 5 and 6).

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."[9] 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."[10]

2. Francis Bacon and the later 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 17^{th} 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.[11] 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 key 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." [12] Thus, in contrast to almost all—even the last century's—philosophers and logicians, he realized that induction cannot be 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. [13]

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 has not really happened: the development of logic has not required 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 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.

Without looking at all the concrete proposals Bacon made regarding inductive learning—most of them are not as important today—I should 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. [14]

Bacon spent great efforts producing many tables, addressing what we would call now the *algorithmic side* of inductive learning. 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 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." [15] Indeed, 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 simply need to be 'extracted' (see the example in Sect. 9 below).

Again, to me, Bacon's main legacy—which, quite understandably, got lost due to the dominance of the numeric formalisms in science—is his insistence on the *universality of induction as both theoretical and practical methodology of science*. By this he meant 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]." [16] 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 accept the Bacon's authority, mainly because of his heavy inductive leanings. So we are left with the one-sided acceptance of his legacy.

The accusations against Bacon—as the greatest prophet of the conquest of nature and as one of several prophets of industrial revolution (accompanied by the neglect of the environment)—are not quite fair. First, he was talking about "conquering nature" in the context of its deeper understanding: "we cannot command nature except by obeying her". Second, even Bacon's genius couldn't have foreseen the recklessness with which imperialism and capitalism have evolved. And third, our inability to *fully* implement his proposals resulted in the one-sided, only superficially "inductive", development of science, which, in turn, has brought us to the present somber state of affairs. Actually, a truly inductive development of science, advocated by Bacon, should bring us much closer to Nature.

As Plato and Aristotle, Bacon also had to deal with Forms, and his concept of Form also 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" [17] 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.

Thus, all attempts by the greatest minds we considered so far to address the concept of Form—or in my terminology, that class representation—could not have succeeded without an *adequate* representational formalism, and, 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 [14].

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). This 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 all our daily routines: 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 Sect. 1.7). 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 [around induction], 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. [18]

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”[19]. However, besides spawning the new area of epistemology (“justification of induction”[20]), 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 [in Hell] 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. [21]

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.” [22]

Nevertheless, if corroborated, the second postulate at the beginning of Section 1.7 *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 *basic* mechanism by which we learn them is universal, the mystery around our inductive capabilities is dissolved. At the same time, two simple points should be kept in mind. First, as I mentioned in Section 1.4, if a given set of examples (e.g. several white swans) from some class (of all swans) happens to belong to a *subclass* (white swans) of that class, 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 its members: classes 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 induction should not be blamed. Induction does not claim that the classes involved are fixed. Again, 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). 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

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-discoverer (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." [23]

At the end of his life, Poincaré was engaged in an important debate with the *logicists*—the growing group of mathematicians and logicians, including 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, eventually, 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. Let us look briefly at what he had to say about the logicists undertaking to 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.[24]
>
> 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 Sect. 1.6.] 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] [25]

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] [26]

As we can see, Poincaré—who also gave us still unsurpassed introspective account of the role of the subconscious in (mathematical) discovery[27]—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 [28], rather than its strength. Indeed, 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? On the one hand, the last century—which, in many ways, was sleepwalking toward the coming radical transition in this century—has seen an increasing number of philosophical, and I would say somewhat 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 discussion 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.[29]) 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, this demand has intensified to such extent that, in addition to the original (engineering) field of pattern recognition dealing with induction, '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 with the problem 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: consequential 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" [30]. 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. [31] 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" [32], 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." [33] 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", discovered in 1945 by Carl Hempel, a German-born philosopher of science who immigrated to the United States, let us first formulate it. Suppose you want to check *inductively* whether "all ravens are black". But instead of looking for actual ravens, you follow the advice of a logician 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 toward the original goal. 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. However, note that while the original task is directly related to 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 there is no "paradox". 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 realized by Aristotle who proposed to *base* logic on classes and induction (see Sect. 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".[34] In fact, quite sophisticated proposals for addressing the non-existing paradox have continued up to the present time, including the paper under the name *The Doomsday Argument and Hempel's Problem*.[35]

Next, consider Nelson Goodman's "new riddle of induction", which, if anything, quite starkly demonstrates the inadequacy of the conventional logical languages for the treatment of induction.

> 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].[36]

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 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'."[37] 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 discuss 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 Sect. 1.6)? 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 need to develop *new kinds* of "logical" languages to deal adequately with the class representation. I also suggest that a complete lack of understanding of the role of generativity in the specification of the class of objects is mainly responsible for practically all misconceptions about the induction. That is all I wish to say about the "new riddle of induction".

Before leaving philosophers, I should mention the anti-inductivist stand by the leading linguist Noam Chomsky, whom I have already mentioned at the end of Section 1.7. The peculiarity of his stand is that, while Chomsky fathered an 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.[38] Ironically, the same computational model, which led Chomsky to deny induction has motivated the development of ETS formalism.[39] I will come back to Chomsky's argument in the last paragraph of this chapter.

5.1 The science and business around the applications of inductive learning

As mentioned above in the section, while some philosophers in the last century were unsure of what to make of induction, engineers and other applied 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, since inductive process—as discussed above—is our *main* tool for making sense of the environment.

In particular, properly developed, inductive learning technology will *unrecognizably* transform search engines as we know them today (actually the leading ones are already relying on some primitive versions of it). What I mean is that in response to your search query, you will be able to get a much more selective set of records that match you query *semantically*, i.e. based on its content, rather than relying on the presence of 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" practically none of the resulting web pages give me the relevant information. Why? First, my query *with the quotes* does not result in any web pages, since there are *no stored web pages with this exact phrase*. Second, since the system is not capable of relying on the semantics of various subphrases involved, it has to rely on the separate words and phrases (without any meaning)—"first", "papers", "pattern", "recognition", "the first", "the first papers", "pattern recognition"—which by themselves do not allow one to adequately interpret the meaning of my query. So, unless there are some web pages containing the exact subphrases from your query *and*, most importantly, *these subphrases capture the meaning of the entire query*, the results of the query will be quite disappointing. Moreover, even when there are some web pages satisfying that condition, the majority of the *semantically* relevant web pages (not containing those exact phrases) will be missing: e.g. "the founding papers on classification."

In view of this, I draw your attention to the amazing fact that *after well over half a century of efforts* by computer scientists our present search engine technologies are still quite primitive, if judged by the quality of the output to a non-trivial search query. Why has the progress in this direction been so negligent? The answer now should be obvious: as will be discussed in Chapter 11, computer science has never dealt with the issues related to semantics, where the latter, I claim, can be properly addressed *only* in the above context of classes and classification. After all, semantics is of perceptual origin (there are no other reasonable alternatives), and hence the meaning of a phrase or of a sentence can emerge only as associated with the abstract class(es) that captures the "meaning" of all semantically equivalent phrases. For example, in the above query, the phase "the first papers" is a member of the class of all phrases that refer to an *inexact* set of historically first papers in the field of pattern recognition. Similar idea, although in a somewhat more muddled form, has also been guiding the development of *cognitive linguistics* [40], a relatively new area of linguistics. We will come back to these issues in Chapters 16 and 18. Of course, I do expect that within the ETS formalism one should be able to 'translate' any query (via structs) into its semantic specification, which appears to be the best possible form of specification.

Let us briefly look at the emergence of the *presently* most popular areas associated with inductive technologies. I recall how in the second half of the 1980s and early 1990s, to get a piece of the large applied 'inductive pie', at first in the USA and then around the world, two 'new' fields (which later merged), coming from completely different directions—but addressing *the same problem of induction*—accomplished a successful coup. They were, first, *machine learning*, coming from the direction of *artificial intelligence* (in computer science), and second, *connectionism* (later called *artificial neural networks*, ANN, now the dominant technology), originally coming from the direction of psychology, specifically cognitive science, though actually relying on the first inductive learning models that appeared 30–40 years earlier. The latest *very popular* "improved" version of ANNs has fancy name Deep Learning systems. (In general, to cover the lack of basic progress, the names in AI have to be impressive, e.g. Deep Mind, the name of a big project by Google.) An ANN has a layered structure: the first (input) layer is a very large numeric vector and all other, sequentially connected layers, consist of many "units" each transforming several inputs (numbers) coming from the previous layer, again, into numeric outputs. But you will be surprised how much 'mysticism' is created around those simple "units".

I devote this short paragraph to the present politics of science. A non-specialist may want to know: How a successful scientific coup in an immature applied field is typically accomplished in the USA? The main path for a group of several researchers, preferably from several universities or research labs, is to convince at least one administrator in at least one major federal agency to begin to fund the new proposal for several years. During this time, using the allocated funds, the group begins to employ new people—often graduate students and postdoctoral fellows—to publish many papers in various journals. That is exactly what happened in both areas. Besides the above two groups, other new groups of researchers also got a piece of the inductive pie, including genetic programming, inductive logic programming, reinforcement learning, and graphical models, which tells you something about the size of the pie and the immaturity of the area.

Although this will draw the wrath of many researchers in these areas, I must admit that no *fundamentally new insights* into the nature of induction were discovered or even proposed. An odd 'exception' is the *syntactic pattern recognition*, where a small group of researchers is still working under the name of "grammatical inference". The direction was inspired by the generative grammars (end of Section 1.7). I can explain the lack of any substantive progress in this subfield by the lack of the 'two-way connection' between a string and the grammar that generates it: a grammar generates the string but the string does not contain enough information for the (inductive) recovery of the corresponding grammar (see also the discussion of string representation at the end of Section 1.5).

The connectionists were motivated by the *architectural* side of the brain, its neuronal systems—hence the original name of the field ("parallel distributing processing") [41]—while machine learning researchers *originally* emphasized formal logic and the computational side.[42] As a result, with a very shortsighted 'help' of the granting agencies, the original field of pattern recognition, instead of consolidating and focusing its efforts within a *single field*, was artificially fragmented into several areas. The only 'positive' side effect of such developments was that many more people, coming from a great variety of backgrounds, were employed. Now, looking back at the ferment and taking into consideration the massive human and material resources that have been and are still being brought in, again, we 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. Note that the present growth in the number of applications of pattern recognition was built into the utility of the field itself, and became possible not due to any fundamental progress in the field but mainly owing to the rapid improvements in the hardware. What are the reasons for this lack of *basic* progress?

As I discussed in Section 1.4, compared to any physical process, induction is a much more abstract, informational, process, and what is more important, 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. In other words, we should view this problem as embedded in *the 'physical' reality* in a fundamentally new way. This implies, in particular, that the superficial *architecture* of the brain and our logical languages cannot help us, as they are incidental artifacts of biological evolution and human history. More importantly, since induction is about the reality of classes and classification, *the key two questions* that should be answered—and which have reverberated throughout the entire history of Western philosophy—are these: *What is a class of objects* and *what is its form of existence?* None of the many areas currently dealing with induction, including the above areas, has seriously addressed these central questions. As has been expected by some scientists and philosophers (see the first epigraph to the first chapter), it appears that the answers to these questions cannot come in a familiar, incremental, manner, as has been previously the case in science, but will *necessitate* a radical change in our basic scientific language. Such *expectation* should not be surprising. On the contrary, given the nature, the scope, and the scientific implications of this problem, a good philosophical grounding should make such expectations quite plain (see the second epigraph to the first chapter). Sadly enough, the present philosophical preparation is extremely poor.

As to such expectation, it is also instructive to recall how two present leaders in 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.[43]
>
> 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 do not 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]. [44]

In this quotation, note, first, quite appropriate very high expectations of the anticipated radical novelty of the new scientific ideas, and second, the acknowledgement of the unresolved search for the "common principles adequate for describing pattern classes of various nature", i.e. of the search for the *general* formalism. However, despite the tenfold increase in the number of researchers working in the areas related to induction, the situation described by the above authors in 1974, for the reasons mentioned before the quotation, *has not* fundamentally changed. Regrettably, this state of affairs has been masked *to the 'uninitiated'* with the help of a massive computational power of our present computers, which in turn allows some propagandists *to fake* a substantive progress where there is none. Of course, the points mentioned in the last paragraph of Chapter 1 (including the declining/transitional stage of our culture) should also be taken into consideration.

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*. Below I consider the case of continuous probability, as it 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 already proposed that the key to unlocking the secrets of induction is a fundamentally new, richer, form of data representation (ETS), since the numeric forms 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*, which is, from the very beginning, *is absolutely inaccessible in those spaces*. But since the discussion of the limitations of conventional mathematical spaces is postponed to Chapter 7, here I approach this topic in a limited way.

Thus, probability theory—though 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, then this point is classified as belonging to the class whose training set of points is located in that part of the vector space. The only reason such *classification* methods, used in practically all (computer) applications, are presently practiced has to do with the *absence of any adequate concept of class*. In this connection, 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 situation more clearly. Most significantly, if *the*

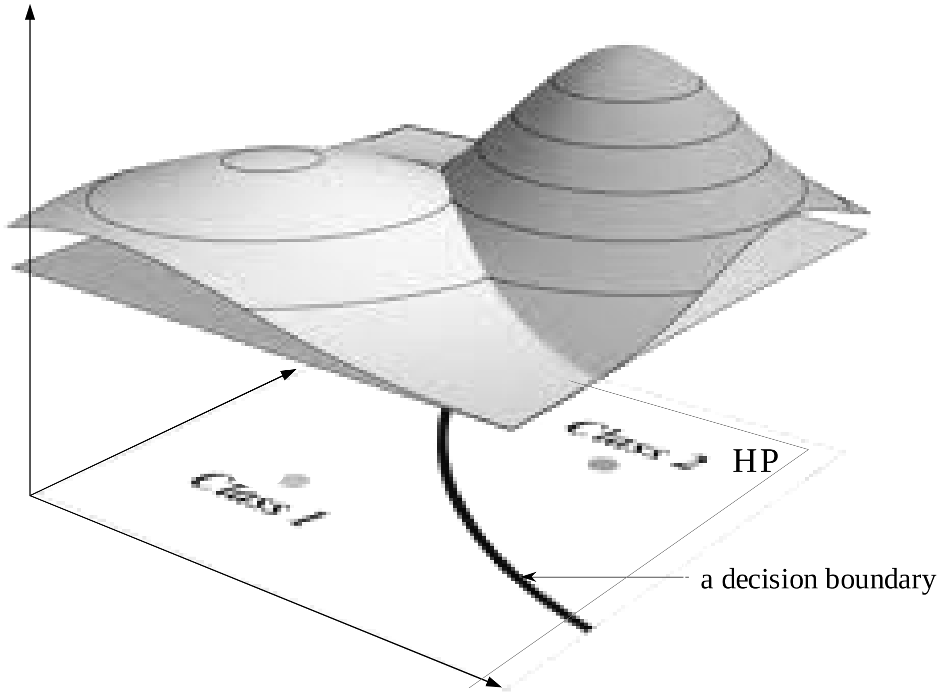


Figure 2.1: The input data is not shown, but each real object is represented by a point in the horizontal plane (HP), while the probability of the object is associated with the vertical axis. Two classes are considered, and each of the two shown probability functions (intersecting surfaces of different 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)

learned classes are, indeed, the main source of all knowledge—as has been suggested by some great scientists (e.g. Helmholtz, see the next section)—how can one believe that the above "decision boundaries" might serve as the source of *any substantive information* about the class or its members? Again, the only reason such evident misconception has not come to light is the *unqualified* acceptance of the numeric representation. 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, which *does* look like a good candidate for the main source of all our knowledge. 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 see the main reason why, after such extensive and intensive scientific and commercial (multibillion) efforts, *no* adequate concept of class—without which induction and classification become quite artificial—has emerged.

So, the probability theory cannot help us with the concept of class, which would not matter much *if* the classes were figments of our imagination, as many still conveniently believe *while practicing classification!* Probability theory is not a magical tool that can *recover the information completely missing from the original data representation*. By avoiding 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 my numerous 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.[45]

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'."[46] 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.[47]

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

> 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.[48]

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][49]

Incidentally, although a good basic science, including mathematics, education appears to be indispensible to a today's psychologist (mainly due to a very abstract nature of information processing), at present, such education is quite rare. The latter, I believe, partly explains the lack of progress with "concepts"—the name for classes in psychology—discussed next.

Helmholtz's 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 began to gain increasing 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*".[50] *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*—originated in the 1970s in the work of Eleanor Rosch and co-workers—has a 'probabilistic' flavor and states that an object falls under 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-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". "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." [51]

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

> [r]esearch into the nature of concepts is ongoing, in both philosophy and psychology, and there is no … 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. … [I]f 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, … some other structure entirely, or no structure at all, is a thoroughly unresolved matter.[52]

Recalling the above remark about the general *scientific* education of psychologists, one should not be surprised at *how far from the physical reality* all the above theories of concepts are, and how scientifically immature they are. Also note a *typical* for many overviews of the present theories of concepts honest conclusion—for which they should be given credit—that everything is basically "a thoroughly unresolved matter". Thus, again, we see very 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 Boethius when translating Aristotle's term "*aphairesis*". The meaning relevant to us has to do with the process of *forming* a general mental image of an object (note the root Form), and we can interpret this meaning as directly related to the process of induction. In that sense, abstraction is the process of forming the 'idea' of a class on the basis of a small number of its members.

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*.[53] 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? 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".[54] 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 10. Some researcher agree with this conclusion, see for example the view of Francis Reilly [55] 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". [56]

Lastly, we deal with universals and particulars, a topic which dates back to at least Plato, but became increasingly prominent 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.[57] A *particular* refers to a concrete object, while a *universal* refers to the characteristics—or properties, or features, or attributes—that are shared by the particulars (in a group of objects). 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 they deny the existence of Plato's Forms. William of Ockham was a leading nominalist, while Peter Abelard tried to reconcile the two positions.

From the ETS point of view, the situation is considerably simpler: we have classes and class representations. And the main question becomes this: Do class representations exist? If they do not, then, I claim, classes cannot exist either. As far as this dilemma is concerned, I am, obviously, a realist. Two issues have complicated the realist-nominalist debate. First, there has not been a clear conception of a class. And second, all these characteristics or properties 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 we know, is in the eyes of the beholder. I also hinted in the middle of Section 5 that what one *might* call universals are 'features' of class representation. The development of a satisfactory concept of class should put all these issues to rest.

9. The missing central concept 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 which a more complete answer to what a class is has to be postponed until Chapter 14 (although see Sect. 1.6). However, in this section, to give an intuitive idea of the proposed concept of class, I illustrate it by presenting a very simple example. To focus on the details, I encourage you to slow down the pace of reading. By way of preparation, review Figures 1.5, 1.6 and the following (informal) rule for attaching events to 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 necessarily 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.)

Mindful of the needs of popular exposition, this *illustrative* example has to be quite simple, although I tried to preserve the spirit of the formalism. Also, *to simplify the drawings, all shown event links are not differentiated* (although actually they are, which calls for a more careful drawing of the structs). Moreover, given a somewhat artificial nature of the example, do not transfer to a general case the 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 the class *Segments*, a member of which is shown in Figure 2.2 on the right. The corresponding structs contain—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 possible that the finiteness of 'physical' objects in Nature might be ensured by the presence of special events.) 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 Sect. 1.6): after the initial step, we have, basically, one repeatable step with the constraint admitting primitive P1 only.

At this point, a general remark is in order, When dealing with '*engineering'* applications of ETS, it is useful to keep in mind that, for any concrete environment, we often have a considerable freedom in the selection of the basic events involved. Thus, it is reasonable to assume that there might be several *different* (and acceptable) *sets of basic events* for such 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 'legal' sequences of events that lead to the formation of objects in this environment. *However, once the choice of the basic events is made, the formative semantics of the objects becomes fixed*.

In our example, when perceiving the resulting geometric (more accurately, topological) configuration—including those in the following figures—keep in mind two points. First, the spatial orientations of the segments (and triangles) is irrelevant and, to avoid crowding, the construction can

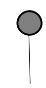
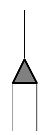
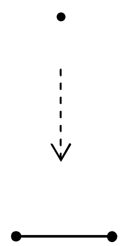
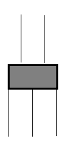
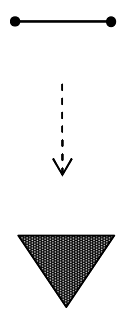
Events	**A spatial instantiation of the events**
	 the unique *initial* event: creation of a point; since this event initiates the generative process, it has no incoming links; this event does not have a label (which would be shown under the event)
 **P1**	 the expansion of a point into a segment; the right outgoing link in event P1 corresponds to the newly created point and the left one, to the old
 **P2**	 the expansion of a segment into the triangle *by fixing one of its ends and pivoting around it*; 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 the second example (left column: depicted geometrical shapes of the events have no spatial connotation). Since the top event can occur *only once*, at the very beginning, focus on the other two events (labeled P1 and P2). The incoming (input) links of each of those two events represent the processes acting on the previously instantiated *extreme* boundary points; 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 one of the above three events (P2 cannot be attached to the first event), the input process(es)/point(s) are *always* 'regenerated' (as the output ones) and are "open for business" again. To simplify the drawings, links of different *kinds* are not distinguished.

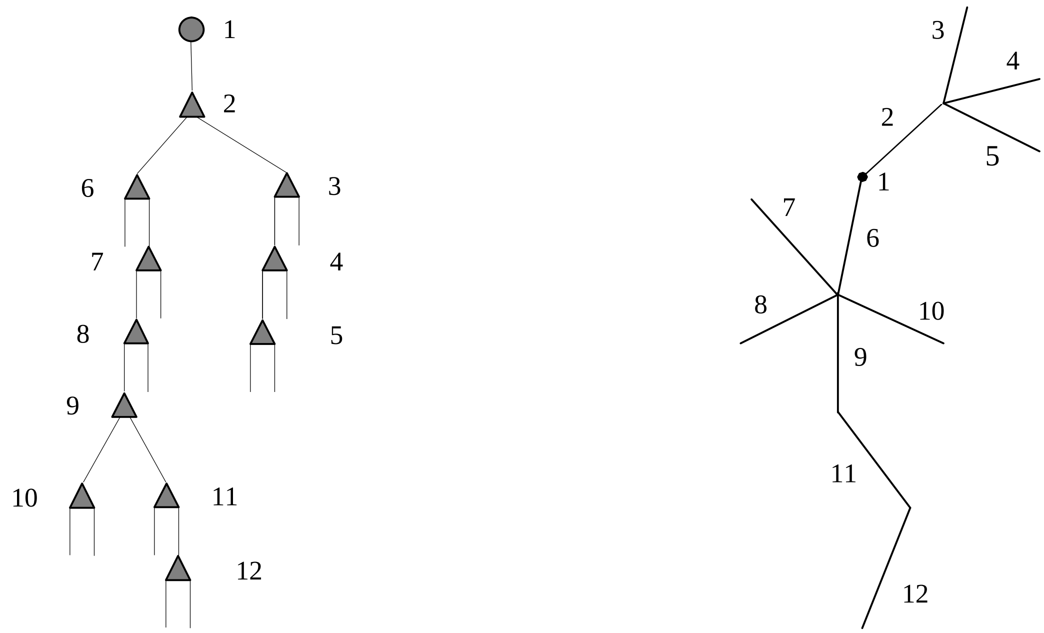


Figure 2.2: Left: Pictorial depiction of a struct from the class *Segments*. The adjective "pictorial" is supposed to sensitize you to the basic fact that, as in the case of numbers, pictures are not the actual abstract representations. The numbers indicate one of several *possible (equivalent)* orderings in which the events in the struct can occur. These possibilities are associated with the fact that only those two events are '*temporally*' related that are *connected by a top-down* sequence of events (e.g. 4 & 6 are not related '*temporally*'). **Right:** the actual object corresponding to this struct.

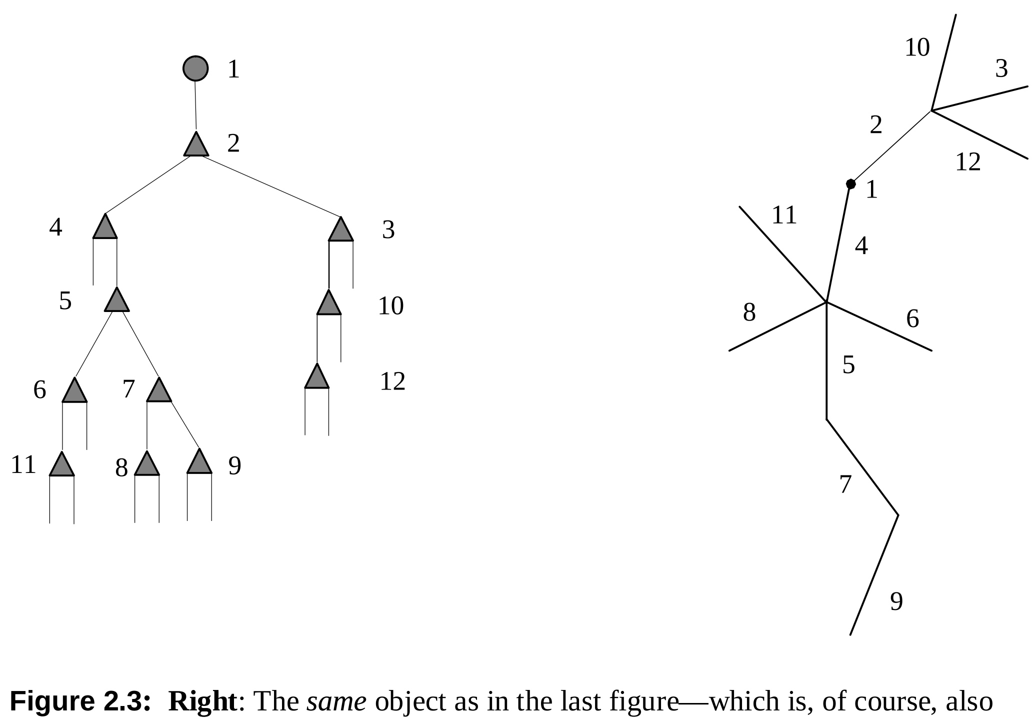


Figure 2.3: Right: The *same* object as in the last figure—which is, of course, also a member of the class *Segments*—but with the order of the events modified. **Left:** Pictorial depiction of the corresponding struct.

be imagined as occurring in the 3-dimentional space. Second, in accordance with the above general remark, 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 the above (very simple) *geometric* patterns 'hides' *many* of its possible *formative histories, or different generating processes.* Thus, in a *very simple case*, shown in Figure 2.2 (right), if we ignore the formative history (captured by the struct) we are *permanently* loosing the 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 usually meaningless*. In our concrete example, when we observe the process of generation for the pattern in Figure 2.2, we notice that the final *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 one) segments with a common origin and then has to be followed by the next branching process that *must* begin at the end of one of the segments just constructed. The only exception to this rule is the very 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 Fig. 2.3 this is not the case, even though it does produce *the geometric pattern identical* to that in Fig. 2.2 (Of course, if it is necessary to define the class based simply on the familiar *geometric* identity of patterns, this can easily be accomplished by eliminating in the class generating process the constraints respocible for the above "branching process" and also relaxing a *fixed* "origin" constraint).

Obviously, more accurate formative information captured by a struct *is an important part of the object generating process and hence of the object itself*, but such information remains inaccessible to the conventional forms of data representation. In fact, without the access to such information—even within such simple class as *Segments*—we would simply *miss many of its "externally invisible" subclasses*, including the just described subclass *Branching Segments*.

I should mention that the above choice of primitives is not *absolutely* foolproof, since the resulting structs do not capture the *exact temporal* histories. For example, in Fig. 2.2, the substruct formed by events numbered 1, 2, 3, 4, 5 coincides with the substruct in Fig. 2.3 formed by events numbered 1, 2, 3, 10, 12, even though each of these two substructs fits differently into the overall *temporal* pattern. In particular, as our (temporal) numbering of events indicates, in the second substruct, events 10 and 12 occurred later than events 4 and 5 in the first substruct. Can we 'improve' the situation in this respect, assuming, of course, that one *does* have access to such precise temporal information (which often is not the case)? Yes, we can. For example, we can complexify the primitives involved. Thus, if greater precision in capturing the generative process is necessary and possible, one extra initial and one extra terminal can be added to *each* of the above primitives: the new links in two primitives would be connected to each other *only* in the case when one of them *immediately* (in a temporal sense) precedes the other. In this way, a more accurate temporal information can be recorded by the struct. In most applications, such option is unnecessary, because the added complexity of primitives complicates the structs without any benefits in return. In our example, the original 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 consider the basic 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", based on which the class representation has to be derived and later used for classification purposes. Without going into the technical details, it is not difficult to see how—given a sufficiently varied training 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 many possible combinations of event P1, the *only* restriction for *the same recurrent step* in the class representation (see Sect. 1.6) that will be learned from the training set is the 'obvious' one: apply primitive P1 only.

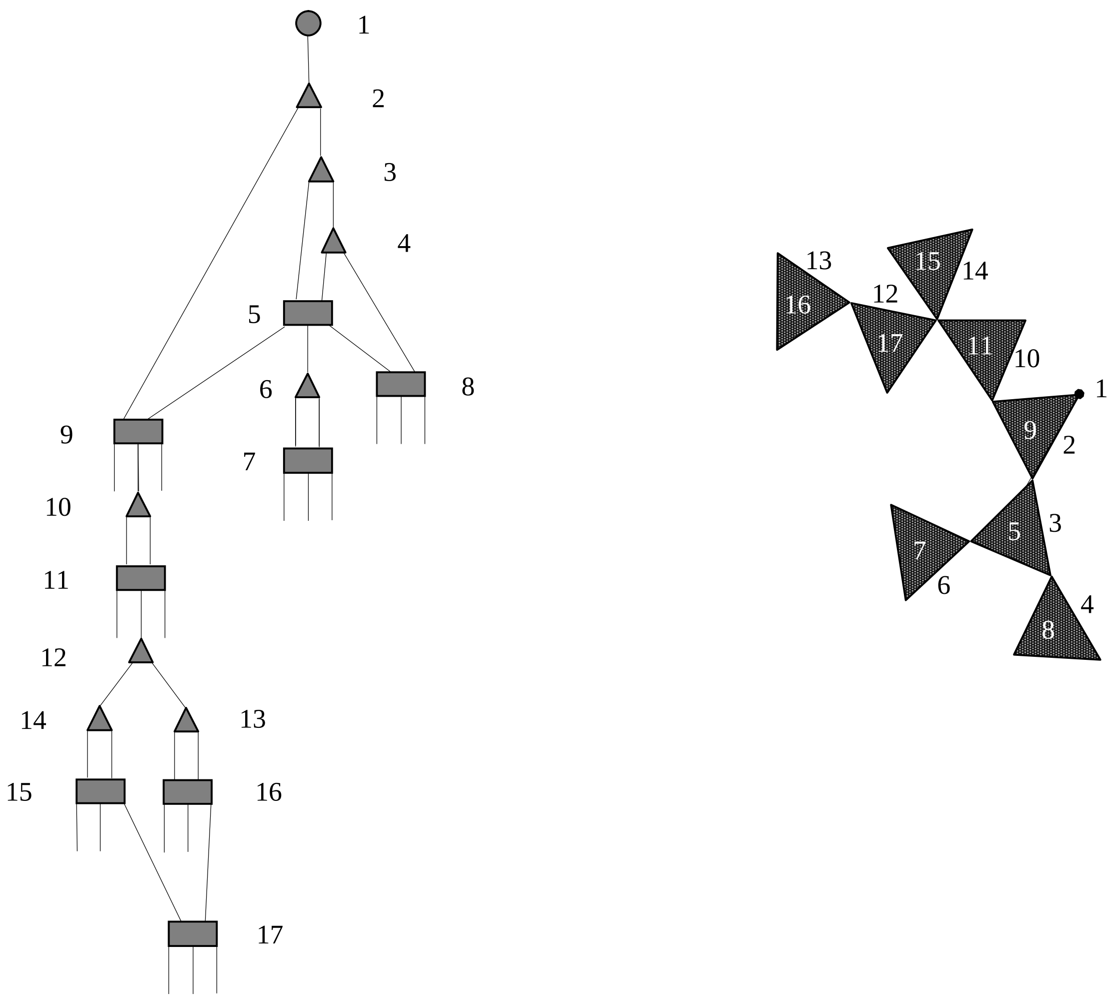


Figure 2.4: Left: Pictorial depiction of a struct from the class *Triangles*. The numbers indicate one of several *possible* orderings in which the events in the struct can occur. **Right:** The corresponding actual (instantiated) object with the corresponding temporal order in its construction, where a number near a triangle's side indicates the corresponding number for this segment, which was later expanded into that (adjacent) triangle.

Returning to the class *Segments*, even ignoring the formative history, this class has, among others, a very simple subclass, *Roads*: it is the set of all linear 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 in the PST environment is *Triangles*: each object in this class is composed of triangles, where each pair of triangles shares exactly one vertex (see Fig. 2.4). Notice that in the shown geometric pattern, a number next to a triangle's *side* means that this side was generated before the triangle and was later expanded (via P2) into that triangle. 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 Volume II, we will come back to the PST world and consider *multilevel* classes in it, when the members of a higher level class are composed of the members of the lover level class.

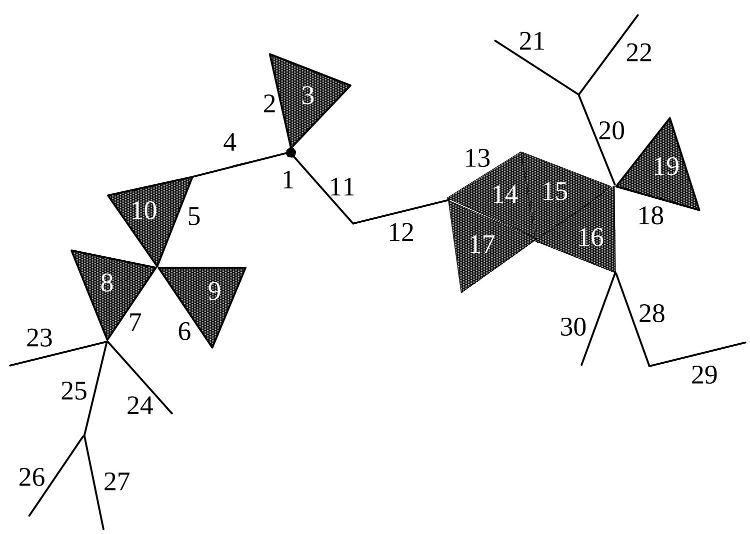


Figure 2.5: An example of a more general object from the PST world. The temporal order of the object generation is indicated, where a number near a triangle's side indicates that this side was later expanded into that triangle. Note that some triangles (15, 16, 17) were not generated in the way just mentioned: each one was generated from the side of a previously generated triangle and this side was not previously generated by event P1.

I should point out that the PST world as a whole exhibits the following general, and somewhat ‘unnatural’, feature. Any fixed existing “point” in the generated 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. 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, since each of them does not transmute the place of application. In this sense, the primitives involved are simplified.

Before leaving this example, several important general observations and questions—to which we will come back in the last chapters of the next volume—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” [58]. The same applies to events: they are quite universal, in the sense that their structure (not their possible spatial semantics) makes them applicable to a variety of 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 kinds of events abound in nature and in non-scientific applications. For example, think of the first cleavage of an 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 1.8, 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 are of purely informational nature (with no spatial connotation), they have quite independent status. Indeed, *does not it make sense, first, that the existence of structs precede the (spatial) existence of the objects to which they may refer, and hence second, that the class representations are stored non-spatially (and dynamically modified) in Nature?* One of the arguments in favor of these hypotheses is that all known object patterns reoccur regularly in Nature and this, in light of the quantum and non-quantum indeterminacies, would not be possible without some informational ‘supervision’ of all the processes involved. If this is the case, the spatial instantiation of objects, as was explained in Section 1.8, does not represent a difficult task, as the corresponding (informational) structs contain enough information to guide such processes.

The above example is supposed to help develop some 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 due to the inadequacy of the present representational means—has been outside the existing considerations in science. (The reason Chomsky’s generative grammars had hardly any effect on the natural sciences has to do with the lack of the corresponding representational formalism to support them more effectively.) In particular, even from the above simple example, it should not be difficult to grasp one of the main points in this book: since *all* objects in the Universe have formative histories, the formative view of objects is their both principal and structural view, yet the numeric forms of representation are intrinsically not capable of capturing it.

10. The unsuitability of human and logical languages as well as numeric formalisms for dealing 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 Aristotle, the founder of logic, was led to the conclusion that induction is a powerful principle *necessary* as the foundation on 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. Later on, during the last century, these obstacles led to a tragicomedy (Sect. 5). The size of the obstacles can be judged by the fact that, as we will discuss in Chapter 9, even biologists, for whom, one would think, *the reality of classes, e.g. of species, in Nature* is so important to the integrity of their science, often go to a great length to close their eyes to this reality.[59]

Thus, all philosophical and conceptual difficulties in dealing with induction stemmed from the *misinterpretation and misclassification* of this problem as logical or philosophical, rather than as a new kind of *scientific* problem. There was no realization that induction is about the reality of *classes* of objects and that the concept of class is a non-trivial concept that cannot be approached relying on one of the conventional scientific 'languages', i.e. induction is above all a *scientific* problem, through which 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 more natural and transparent. But what kind of representational formalism (Sect. 1.1) do we need?

In answering this question, I believe, we should follow, first, Aristotle's suggestion that biological organisms are simply more sophisticated representatives of all objects in Nature, and so what biology tells us about its objects should be generalized to all objects. Indeed, the first step toward the mind-matter duality, the main source of our present scientific troubles, is the animate-inanimate duality. Moreover, as mentioned in Section 1.4, it is highly unlikely that biological evolution came up with a *fundamentally new* form of object representation: even if one were to imagine such discontinuity in the evolution of the Universe, the corresponding development would have disrupted the connection with the previously existing processes that had relied on the original form of object representation. At the same time, biology—particularly developmental biology—suggests that all objects may have developmental, or formative, histories, and that the 'glue' that binds 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 representational formalism we are looking for should *immediately* explicate the concept of formative structure, i.e. it should embody this concept *directly in its form of representation*. Actually, for *any* representational formalism, including numeric, the representation that it offers does come 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 formally constructed.

In connection with the role of generativity in inductive processes, I should *at least* mention here the relevant view on induction expressed by William Whewell (1794—1866), a noted British historian and philosopher of science. When debating induction with John Stuart Mill, Whewell suggested a non-standard view of induction, to clarify which he introduced a new term "data colligation." [60] This term refers to the process that he considered the key to induction: the process of coming up with a 'generative' conception of the data given in induction (if I may modernize his view). In our terminology, this term might be considered as an intimation of the construction of a (generative) class representation during inductive learning.

So, it should be clear that, first of all, any human or logical language was not developed and is not suited for the purpose of capturing *formative* object histories, where the latter are critical to the inductive considerations, hence all the 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, information *to which this point has no relation*? 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, several remarks are in order. First, I should at least mention here the non-technical, not related to any form of representation, and not *directly* referring to induction, but in many ways similar to our proposal, contributions of former molecular biologist Rupert Sheldrake, which he has advocated starting from the early 1980s [61] (we consider them in Ch. 12). His informal "morphic fields" and "morphic resonance" may be viewed as analogous, correspondingly, to the class representation and the generation of new class elements. Second, I would like to come back (see Sect. 1.7) and critically evaluate the "poverty of the stimulus" argument [62] introduced in linguistics by Noam Chomsky. The argument is that the grammar—that each of us is relying on when we exercise our mature language skills—is too complex for learning it during the brief exposure a child has to a relatively small number of sentences. Based on this argument, Chomsky concluded that induction is irrelevant, and hence he proposed the "innateness hypothesis", i.e. there exists a single "universal grammar" which is (genetically) innate to all of us. This hypothesis became quite controversial, since if accepted it 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 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 again to one of, if not the *main reason* why—quite unexpectedly to almost all scientists—induction *is* supposed to play the pivotal role in the coming radical scientific change we are discussing in this book. It appears that this reason is the indispensible and, at the same time, quite transparent role of *structural* representation in inductive processes, and in the concept of class of objects in particular. As we discussed in this chapter, such role is not as surprising as it may seem at first: starting as far back as twenty three centuries ago with Aristotle, a number of great philosophers and scientists had already pointed out the critical role of induction in epistemology (read information processing) and science.

Notes

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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, $A \vee B$ (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, underlying, or 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 formal 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/axiomatic 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 was treated in Chapter 1 and will also be treated in Chapters 5 and 7.

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 gestalt, or the overall, comparison of the two groups of objects (e.g. $***$ vs. •••••), and the search for individual objects (e.g. the presence of a particular dog). 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, 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 definition[2], 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 observe 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 a 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 underlying and the present formal concepts of natural number, where the formal concept is considered the most basic (and most satisfactory) definition in all of mathematics. Considering the millennia old predominance of spatial connotation of numbers, we should take *this formal need* to rely on the temporal construction in such basic definition as quite significant, especially given its *relatively recent timing (the end of the 19th century)*.

But first, let us 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 if indeed—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 in fact, this turns out to be the case, as the following several, *out of many known*, examples testify.

Thus, only "proving they can do math across different senses," rhesus monkeys can match *the number* of sounds they hear to *the number* of shapes they see.[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 that even bees can learn to discriminate between small quantities, and she adds: "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 $\boldsymbol{N}$ of **natural numbers** is defined as a set of elements satisfying the following axioms, or postulates:

1. $\boldsymbol{1}$ is an element of $\boldsymbol{N}$.
2. For each natural number $\boldsymbol{n}$ there exists (among natural numbers) the unique successor $\boldsymbol{n}^+$, distinct from $\boldsymbol{n}$, such that if for some natural number $\boldsymbol{m}$
$$\boldsymbol{n}^+ = \boldsymbol{m}^+ \text{, then } \boldsymbol{n} = \boldsymbol{m} .$$
3. $\boldsymbol{1}$ is not the successor of any natural number, i.e. there is no natural number $\boldsymbol{n}$ such that $\boldsymbol{n}^+ = \boldsymbol{1}$.
4. (The axiom of induction) If *some* subset $\boldsymbol{M}$ of natural numbers contains both $\boldsymbol{1}$ *and* the successor of *every* number in $\boldsymbol{M}$, then $\boldsymbol{M}$ *must* coincide with the entire $\boldsymbol{N}$.

The second axiom is typically split into two axioms. Also, from this axiom it follows that the set $\boldsymbol{N}$ 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 *significantly* from the other axioms above as well as from axioms, for example, of geometry, both in appearance and substance. It differs in appearance since it is about special kind of *subsets* of $\boldsymbol{N}$. 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]

Nonetheless, 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 (in Axiom 2) on *the successor operation S* assigning to each number $\boldsymbol{n}$ its successor $S(\boldsymbol{n}) = \boldsymbol{n}^+$. To simplify the exposition, I avoided the explicit use of the successor *operation* and used instead the notation $\boldsymbol{n}^+$, while more formal expositions of the Peano axioms *explicitly* use this 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.

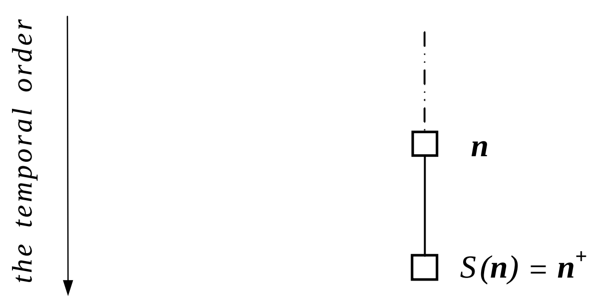

Figure 3.1: Pictorial illustration of the *temporal* (Dedekind-Peano) structure of natural numbers.

Concluding the section, I wish to clarify Poincaré's profound evaluation of the epistemological role and place of induction in the overall structure of our knowledge. In the following, I am quoting from [8]:

> For Poincaré, arithmetic intuition is what enables us to have access to the following cluster of key concepts: 'indefinite iteration', (potential) 'infinity', 'and so on', 'etc,', and the principle of induction. The [immediate physical] world does not provide us with an indefinite iteration; indeed, if anything, the world falsifies any actual attempt to instantiate the concept, since we each only live a finite amount of time.[9] So we cannot *acquire* the concept of indefinite iteration. So the ability to comprehend the concept must be given a priori.

> Further, we cannot formally reduce any of the key concepts either. Any formal explication of a concept which denotes an iterative process, will necessarily involve a procedure which is itself iterative. …
>
> … [Poincaré's] point is that the essence of induction is much deeper than a truth by definition of some particular formal structure, or some particular class of formal structures. Rather, it is what enables us to construct formal structures in the first place. Induction is a property of the human mind: the intuition of induction underlies the general ability to think systematically. Knowledge of induction is a priori, because it is not empirical, or reducible to experience ….

In connection with the exceptional and prophetic view of Poincaré, I should draw your attention to how our ETS formalism (i.e. class representation, class generating system, Sect. 1.6) clarifies the a priori nature of all generative constructions.

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

An interesting question related to the topic of the section is this: What is a possible early triggering event in the history of science that have played a significant role in the later chain of events responsible for the permanent *spatialization* of numbers. (Of course, the concluding stage of the latter process was 'officially inaugurated' much later by Descartes and Fermat, including the "coordinate system" and "analytic geometry", and will be addressed in Chapters 5 and 7.) Besides the main and obvious reason, associated with the by far our dominant mode of perception (vision), it seems to me that a good candidate for the above triggering event is 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. In the modern language, this was the discovery of 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.

So the way very mysterious irrational numbers came into mathematics is via *geometric*, or again *spatial*, route. Of course, in view of the dominant role of *spatial* measurements in various cultures, no one would have questioned the expediency of such addition. Moreover, even today the same expediency, or rational, would still apply: 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." [10]

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

The driving force behind this displacement may be briefly described as follows. 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 powerful formal "language"* for expressing more accurately our knowledge about the external world. Of course, in addition to the logical beauty of this language, it was the sense of sight, our by far the most powerful sense, that also guided and promoted the corresponding processes, including acceptance of various geometric constructions as *physically real*.

As will be discussed in the Chapters 5–7, 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 1.9 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 characterized by yet unrecognized and unprecedented crisis in science. I suggest that 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 theoretical schemes that are *far removed from the original temporal connotation* of that concept. 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, as a result, have been unable to deal *adequately* with the (central) issue of time in science. And 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 hart of our present mathematics*, which obviously, has had enormous implications for our perception of 'physical' reality. The present 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.

Given our present scientific experience, it should not be surprising that 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 its *most natural (temporal) generalization*, which may show us the way out of the spatially-based science. After all, we don't have any other candidate concept for the relevant generalization that is even remotely comparable with the natural number in its decisive influence in shaping our civilization, including our science.

Notes

1. A. P. Yushkevich (ed.), *History of Mathematics*, Vol. 1, Nauka, Moscow, 1970, p. 9 (my translation from Russian).

2. Michael Hallett, *The Cantorian Set Theory and Limitation of Size*, Oxford University Press, 1996, p. 121.

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

4. Wikipedia contributors, Bird intelligence (section Counting), *Wikipedia*, http://en.wikipedia.org/wiki/Bird_intelligence [accessed 7/06/2013].

5. See note 3.

6. Henri Poincaré, *Science and Hypothesis*, in Henri Poincaré, The *Value of Science: Essential Writings of Henri Poincaré*, The Modern Library, New York, 2001, p. 19.

7. Henri Poincaré, *Science and Method*, in Henri Poincaré, *The Value of Science: Essential Writings of Henri Poincaré*, The Modern Library, New York, 2001, p. 571, slightly corrected by me.

8. Janet Folina, *Poincaré and the Philosophy of Mathematics*, St. Martin's Press, New York, 1992, pp. 107–9.

9. Henri Poincaré, *Science and Hypothesis*, Dover, New York, 1952, p. 22.

10. B. L. van der Waerden, *Geometry and Algebra in Ancient Civilizations*, Springer, Berlin, 1983, p. xi.

Useful terms

Peano axioms– the standard (in mathematics) set of axioms for natural numbers, which were first proposed in 1888 by Richard Dedekind and then, in the improved version, in 1889 by Peano

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 radical quantification road to the Scientific Revolution

1. **The underappreciated first scientific revolution: The emergence of science in the 5^{th}–3^{rd} centuries B.C.**

2. **Europeans discover a very attractive 'sinful' path out of the Dark Ages: Quantification of Western society in 13^{th}–16^{th} centuries**

3. **The present-day implications of the emerged measurement culture**

4. **Conclusion: The seeds of both its success and decline were planted into the very core of the Western quantification culture during 13^{th}–17^{th} centuries**

Chapter 5

Crossing the Rubicon: Not unexpected fateful philosophical and scientific decisions by the fathers of the Scientific Revolution

1. **My selection of the key fathers of the Scientific Revolution: Galileo, Kepler, Descartes, Huygens, Newton, and Leibnitz**
2. **Some preliminary works in the science of mechanics in the 16th century**
3. **The two-stages transition to the new cosmology**
4. **Matter 'becomes' a structureless substance not subject to becoming**
5. **The dominant role of space in the development of science: Spatial extension as the essence of material substance**
6. **The emergence and evolution of the modern concept of space during the Scientific Revolution**
7. **The deliberate elimination of the "informational" from the science of mechanics**
8. **The physical concept of force and a hint of how mechanics (physics) was constructed**
9. **The implicit elimination of time: Its subordination to the concepts of space, matter, and motion**
10. **The corpuscular-kinetic view of Nature**
11. **On the entrenched connection between the physical and the mathematical**
12. **Conclusion: Numeric mathematics as the divine tool for organizing the Universe**

Chapter 6

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 7

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 8

Some consequences of building physics on the spatial foundation

1. Physics as a science of motion (in space) and its profound effects on our society

the role of Laplace in the separation of physics (science) from the "reality"

2. The adventures of the concept of force

3. The non-spatial nature of energy and waves (their ephemeral nature)

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

5. The artificial nature of Minkowski space of special relativity theory: Time as a spatial 'dimension' non-commensurable with space

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

7. Quantum mechanics: Continuous formalism for a discrete phenomenon

Quantum indeterminacy relations as invalidating both the physical applicability of the differ.–integral framework and of 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: New physical concepts as the old ones 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 9

Some consequences of basing other natural sciences on the spatial foundation

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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 10

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

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4. The inadequate integration of perception in psychology

5. Why Chomsky's concept of generativity could not sufficiently influence the development of cognitive science

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The false expectations of computer science

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2. No commitment to a representation

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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

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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

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

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The inseparable concepts of class and class representation

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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

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Transformations and representational stages

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

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2. **The amazing unity of syntax and semantics**
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The structural, or temporal, view of reality and the natural sciences

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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 18

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**

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Chapter 19

Conclusion: We are about to embark on our greatest adventure

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3. The new scientific outlook should catalyze the social transition