REDOING OUR MATHEMATICS AND SCIENCE

INTEGRATING MIND INTO THE UNIVERSE

Chapters 1 & 2 **+** preliminary outline of other chapters

This book proposal is being continuously modified, so rely on the latest version.

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Contents

Chapter 1

Introduction: The pressing need to start our scientific journey anew

> [My] profound conviction [is] that *the foundations of science as a whole and of physics in particular, await their next great elucidations from the side of biology, and especially from the analysis of the sensations* …
>
> [and that a new] science … embracing both the organic and the inorganic shall interpret the facts that are common to the two departments.
>
> Ernst Mach

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

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

1. The language of science: Scientific formalism

Since we are going to discuss why our science needs a fresh start, let us begin with the absolutely basic yet completely neglected issue laying at the foundation of all science.

What is the main distinguishing characteristic of our basic natural sciences? Surely, it is the special 'language' they rely on. And although the use of numbers and measurement processes is not peculiar to science alone, the highly developed apparatus around the numeric language is unique to science.

Let us fix the term **scientific formalism—**or more relevantly, **representational formalism—**for a particular form of *data representation* (plus the corresponding apparatus) that scientists simply *have to rely on in order to collect and process data*. Such formalism is the *scientific spectacles* through which we see the reality, since all data is being collected in this particular form. So the basic component of a scientific formalism is its **representation set**: the set of entities chosen to represent, or stand for, the actual objects. Generalizing our present situation in science, we will assume that such entities *do not have to be of numeric origin only*, see Figure 1.1. (For simplicity, the noun 'object' will be mainly used in the most general sense, including 'process'.)

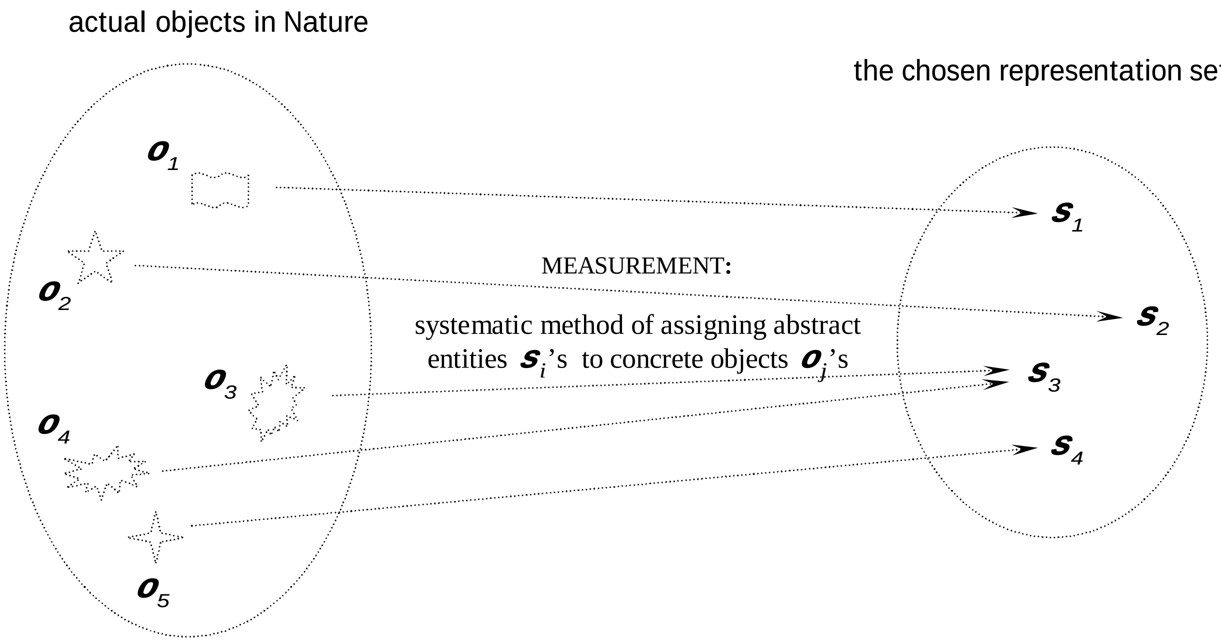


Figure 1.1: The concept of a representational formalism: each s_i (i = 1, 2, 3, …) '*represents*' the object o_j on the left to which it has been assigned. In general, s_i does not have to be related to numbers or be a *point* in some abstract space.

For historical reasons, discussed in the next several chapters, so far, our science has relied on a *single* representational formalism, which I will call **the numeric formalism,** also associated with the numeric measurement processes. In this formalism, numbers or *a variety of numeric aggregates*—e.g. complex numbers, vectors, matrices, functions—constitute various 'parts' of the above representation set, i.e. we *represent* actual objects and processes by means of such kinds of abstract (numeric) entities. In particular, we substitute for an actual object *a point in some abstract space* identified by its numeric 'coordinates', which could be its position, size, speed, brightness, etc.

Hence, when viewing our scientific enterprise in its entirety, its systematically overlooked or *taken for granted* part is the above 'numeric glasses' we must wear 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, by now our scientific and everyday life is dominated by the questions "how much", "how big", "how small", "how long", "how far", "how heavy", etc. Yet when we look at a tree or at a face, what draws our attention above all is its 'individuality', or 'peculiarity'. Sages of all times have agreed that this 'individuality' is of a qualitative rather than of quantitative nature, and that is why 'quality' and 'quantity' are often rightly considered antonyms. According to the *new scientific* point of view outlined in this book, our perception is not as naïve as most scientists would want us to believe.

The numeric form of data representation, which we will discuss in detail in Chapter 7, was fully sanctioned during the so-called *Scientific Revolution*, mainly of the 17th–18th centuries. This "revolution" immediately followed the unprecedented general cultural shift from qualitative to quantitative perception in Western Europe during the previous three centuries. The shift was even more impressive because it affected not only the activities related to measurement of time and space—including the spread of mechanical clocks, marine charts, and double-entry bookkeeping—but also music (notes) and painting (perspective).[2] Of course, the Scientific Revolution was the continuation of our at least forty-thousand-years-old numeric history, especially the forgotten Hellenistic scientific revolution, discussed in Chapter 4. So one might say that the former Scientific Revolution built the numeric 'train', but the numeric 'rails' for it had been ready for a very long time.

Given our long and pervasive numeric history, it is not surprising at all that until the advent of computers—which within several decades brought to the fore the general question of *object representation*—the issue of a non-numeric form of representation as the substitute for the numeric representation could not have even arisen.

In the first half of the book, we will discuss the structure and the basic *inherent*—i.e. related to the structure of the formalism itself—limitations of the *numeric form of representation* (where s_i in Fig. 1.1 is a 'point'). This representation plus the continuous orientation on the preliminary understanding of the *inorganic* processes have completely defined the development of mathematics, natural sciences, and all data processing by computer, and most importantly, it is responsible, as we will see, for a one-sided yet unnecessarily confusing view of Nature.

Historically, the use of numbers has been a predictably ever-expanding affair: from *the temporal origin of natural numbers*, discussed in Chapter 3, to counting to measuring and then to *object representation* (via numeric coordinates). It is the latter that is the main culprit whose emergence can be traced to the shift from the temporal to the *geometric, or spatial, considerations*, in the ancient measurement practices. I will argue that during the Scientific Revolution—which adopted the *view of objects as composed of points in the three-dimensional space*—numbers were brought into the 'representational business' through this quite understandable but, as it turns out, both *formally and physically* immature view of 'matter'.

We will also see that *the natural* number—not only as it initially emerged in the pre-conceptual form, but even as it is axiomatically treated in mathematics—*is a temporal concept*. The use of numbers for counting purposes was quite harmless. However, as the 'original sin' of using numbers for *representational* purposes began to be exploited to the full and with remarkable genius by the participants of the Scientific Revolution, numbers have since been 'recruited' for all kinds of 'non-counting' purposes, in order to measure, eventually, anything we fancied, including time, energy, and even happiness. Motivated by applied geometric (again spatial) considerations—first, by the irrationality of $\sqrt{2}$ and later by the calculus—natural numbers were *extended to the real numbers*, and their *temporal origin* was completely overridden by the *spatial* connotation of this, much larger, set, to the effect that time itself was turned into a mere extra 'spatial' dimension and hence, effectively and quite conveniently, eliminated (Chapters 5–9).

Today, when the resulting numeric formalism has run into substantial conceptual difficulties, for example in quantum mechanics, where a continuous formalism has to model a fundamentally discrete reality, *the true, purely calculational*—or, increasingly, the famed "shut up and calculate" [3]—face of this formalism has become quite apparent. At the same time—as was convincingly argued by the late American philosopher of science Milič Čapek[4]—the early discovery in the same quantum mechanics of *quantum indeterminacy* and quantum 'fluctuations' have exposed the fundamental inadequacy at the quantum level, and hence at all other levels, of the (numerical) conservation laws as well as of the basic physical concepts, e.g. energy, time, mass, moment.

So, gradually, the 'original sin' has caught up with us in science and also managed to do enough damage to our morals and social structure (see the quotations in the next section). We need to correct this situation by shifting from the *numeric* to another, more appropriate for that purpose, object representation. These are the questions I have been thinking about and working on since the end of the 1970s: *How can we move beyond our numeric formalism and what will the Nature look like through the new, non-numeric, spectacles?*

In light of our experience, it appears that the *only* possible way to *significantly* expand our scientific horizon is by expanding the numeric representation to a fundamentally new, i.e. *non-numeric, representation*: no fundamentally new form of data representation, no fundamentally new scientific paradigm. In other words, to move beyond our numeric scientific paradigm—the only one we have had—one must replace the numeric form in which *all our data, including images, is being collected and processed*, something that *may* appear quite impossible!

In order to address this, new, kind of scientific formalism—where the results of 'measurement' are not numbers—let us give it the name **structural formalism**, or **structural representation**. The adjective "structural" is supposed to suggest that *each* member s_i of the representation set (see Fig. 1.1) *is not a point, or some unstructured entity*, but a structural entity composed of *interconnected units*—each with its own structure and each having the incoming and outgoing links—so that, from the very beginning, the emphasis is not only on the units but on their interconnections (see Fig. 1.5).

In the formalism discussed in this book, first, it is postulated that the 'true structure' of an actual object o_j (in Fig. 1.1) is to be understood as the object's '*formative structure*', or '*formative history*'. Such structure is captured by the actual events *in Nature*—the above "units"—that took part in the formation of that object. Indeed, any object *should* be viewed as *the result* of the corresponding events since they 'produced' it. Note the noun "event", which will be given later a formal meaning. Second, *from an 'external', or agent's, perspective,* the construction of the representation s_i of the object o_j can be viewed as the 'simulation' (by the agent) of the object's formative structure. So, the object's actual, or complete, formative history is being 'simulated' relying on *the agent's* arsenal of events. The key idea here is the concept of formative object history, or structure, which is hypothesized to be ubiquitous in the entire Universe and not restricted to organisms only.

Ironically but quite logically, there seems to be no other reasonable way out of the numeric representation except by *returning to the only reference point we have—the original temporal form of natural numbers—and generalizing this form* (Figs. 1.4 and 1.5). Such generalization is possible and will be preliminary outlined in Section 4; in fact, this book was motivated by the implications drawn from such structural formalism.

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

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

We should expect the new formalism to address the needs of *all* sciences much better than its predecessor. The candidate for such a formalism outlined in this book promises not only that but also accounts for the nature of induction—including the nature of classes (of objects) in the Universe—the nature of time, as well as the nature of 'emergence'.

On the formal side, our development of structural representation was motivated *by bringing the 'structure' immediately, at the level of object representation, rather than 'indirectly', via spatial and numeric, including geometric and algebraic, mathematical structures*. Hence, the new mathematics, once developed, can be much more legitimately (than the conventional one) called structural.

Again, the numeric formalism became the *representational* formalism during the above Scientific Revolution. Originally used strictly for accounting purposes—e.g. seven pigs or five measures of barley—numbers are *not suited for representing objects or processes themselves,* for which purposes they are used now. For example, a person's or a car's mass, volume, or energy, convey hardly any information about their *structure,* and as we shall see, *an object's representation should all be about the object's structure*. Indeed, if a particular vehicle and a particular tree have the same mass, this provides very little information about the two objects. Moreover, if, in three month, a mature tree grew and its mass has increased, its *basic* structure has not changed, and, indeed, we would be able to recognize it as the same tree, which suggests that that our minds' *representation* of the tree is not numeric. To repeat: the main information to be captured in the object's representation is the object *structure,* where the very concept of 'structure' is to be elucidated by the representational formalism. It appears that all organisms rely on the representations of that kind. So *the true scientific revolution*—associated with the transition from the quantitative (numeric) to the qualitative (structural) description of Nature—is still ahead.

It is also quite natural to anticipate that humankind is not going to go through many different representational formalisms, simply because each consecutive one should bring us significantly closer to the actual phenomena in Nature or society. In fact, if the two hypotheses about the structure of reality proposed in Section 5 will be validated, we may need to undergo *just one* such transition: the structural representation proposed in this book is already supposed to be *a 'mirror' copy of the structure of actual processes* in Nature!

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

In Chapter 6, we will discuss the mind-matter split, which *was postulated by the fathers of the Scientific Revolution and, on the formal side, has been sustained by the numeric framework.* Influenced by the dominant at that time clockwork technology, this split was motivated by the pervasive at the time view that the Mind, in the form of the Creator, designed and produced all of Nature, remaining outside it. Furthermore, it was assumed that, since our minds originate directly

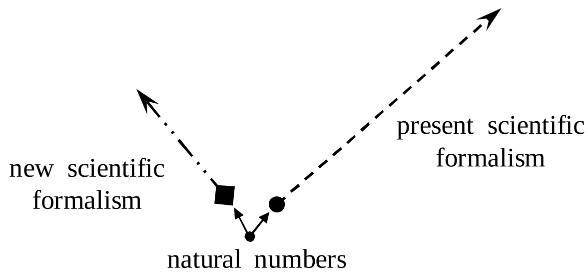


Figure 1.2: Our scientific 'train' is moving in one direction, and it cannot be redirected midway in an entirely different scientific direction, simply because the design of the 'rails' for the latter is based on a *fundamentally different form of data representation.*

from the Mind, they are also outside *the 'material' Nature—which is based on the mechanistic principles*—and have hardly anything in common with it. However, the *decisive assumptions,* for the present state of affairs, were not so much the mind-matter split as such but the resulting two implicit working assumptions, reasonable *at that time*, that, first, one should not be concerned with the mind part (since there is nothing scientific one could say about it), and second, that the 'material', spatially extended Universe can be adequately modeled relying on the numeric and geometric considerations.

Since then, first, "the Mind" part—and hence, *according to the above assumption*, also "the mind" part—have completely disappeared from the main scientific picture, despite some vague appeals to mind in quantum mechanics and the desperate attempts by neuroscientists, psychologists, and artificial intelligence researchers to 'rediscover' it. And second, the original 'material' orientation—in the form of its spatial connotations—has become synonymous with *the* scientific view of Nature, despite the practical elimination of the atomic hypothesis of matter in the ubiquitous concept of field and the increasing complication of the resulting picture.

I will argue in Chapters 5–7 that, as it turned out, *on the formal side*, the mind-matter gulf has been sustained and entrenched by *the intrinsic structure of our numeric formalism* (which has also been responsible for the implicit elimination of time in physics). And because this gulf cannot be bridged within the numeric framework, the heading of this section suggests the main reason why we need to start our scientific journey essentially anew (Fig. 1.2), in order, finally, to *liberate ourselves from this unnatural split by integrating mind into the Universe*.

Although such new beginning could not have been productively embarked upon until the second half of the last century, it is long overdue. Here are just several relevant observations made during that century, interestingly enough, not by scientists but by the historians and philosophers of science. The first one is made in 1965 by the prominent late French historian and philosopher of science Alexandre Koyré, who coined the phrase "Scientific Revolution":

> Yet there is something for which Newton—or better to say not Newton alone, but modern science in general—can still be made responsible: it is splitting of our world in two. … [The 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, through there is place for everything, there is no place for man. Thus the world of science—the real world—became estranged and utterly divorced from the world of life, which science has been unable to explain—not even to explain away by calling it 'subjective'.

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

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

This is the tragedy of the modern mind which 'solved the riddle of the universe,' but only to replace it by another riddle: the riddle of itself. [5]

The second, somewhat harsh but quite perceptive observation—which will become more apparent as we progress through the book—is made in 1932 by the late American historian of science and philosopher Edwin Burtt, also one of three-four pioneers of the modern view of the Scientific Revolution:

It does seem like strange perversity in these Newtonian scientists to further their own conquests of external nature by loading on mind everything refractory to exact mathematical handling and thus rendering the latter still more difficult to study scientifically than it had been before. Did it never cross their minds that sooner or later people would appear who craved verifiable knowledge about mind in the same way they craved it about physical events, and who might reasonably curse their elder scientific brethren for buying easier success in their own enterprise by throwing extra handicaps in the way of their successors ...? Apparently not; mind was to them a convenient receptacle for the refuse, the chips and whittlings of science, rather than a possible object of scientific knowledge. [6]

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

To insist on trying to explain the mind in terms of concepts and theories that have been developed exclusively to explain nonmental phenomena is, in view of the radically distinguishing characteristics of the mental, both intellectually backward and scientifically suicidal. The difference between mental and physical [as we understand it now] is far greater than the difference between electrical and mechanical. We need entirely new intellectual tools … [7]

And finally, here is a more recent observation by Ian Marshal and Danah Zohar regarding the social consequences of the resulting scientific view:

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

The sharp divide between the observer and observed in mechanistic science, and the accompanying picture of a physical world composed of lifeless, brute matter, places human beings and their projects outside the context of nature. Nature becomes an object, something to be observed, conquered, and used. Technology is a means to this end. Today's ecological crisis is in large part the product of such thinking, but *we have no new overall model of nature, nor of a relationship between the human and the natural, from which we might derive new thinking*. [The last italics are mine] [8]

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

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

Moreover, there are also many reasons to believe that—as was the case with our current scientific paradigm—the structural paradigm should change our moral, social, and economic climates. However, in this case, the elimination of the mind-matter split can only harmonize our relationship with Nature rather than contribute to a further degradation of our environment. Already in this chapter, we will see why numbers—introduced originally for accounting purposes but later recruited as an (extremely simplified) *form of object representation*—decisively contributed to the many dead-ends our society is currently facing. Although I do not focus on such issues, they might be the most important considerations in favor of the structural scientific paradigm.

Surely, there would be no urgency in addressing the above split if there were no clear alternative to the existing scientific paradigm. And it is this alternative, within which the engendered split is obviated, that will be outlined in the book.

Many of us have a strong intuition that we live in transitional times, both socially and scientifically, although we do not know which of the two will lead the way. But the important general question regarding this *scientific* transitional period is this: *How radical will this transition be?* Is it going to be *conceptually*, more or less, incremental, as the previous transitions, or non-incremental? Quite understandably, since scientific models have been replacing for scientists the spiritual ones, with all the emotional connotations, the vast majority of scientists simply shut out the much more painful for them possibility of a non-incremental change—also because such change would be accompanied with an incredible 'deflation' of their professional competence.

From the above, you can intuit my answer to the same question: I believe this conceptual transition is going to be more radical than the humankind has ever experienced since the emergence of numbers and cities, and in this section I mentioned a radically new, non-numeric, form of data representation and the elimination of the mind-matter split as two possible reasons. Some other, concomitant, reasons will be discussed in this chapter and throughout the book. However, my answer should not surprise you at all: to remove the mind-matter split—or equivalently, to bring mind into the main scientific picture—is an unprecedented undertaking with enormous benefits, but as the saying goes, "there is no such a thing as a free lunch". In the last century, there have been many leading scientists, including Schrödinger, Einstein, Heisenberg, and many philosophers, including Bergson, Whitehead, Čapek, who have anticipated this (non-incremental) answer. Here is just one of such assessments of our period expressed in 1986 by the late American philosopher Ivor Leclerc:

> … contemporary scientific development has thrown into question in an extremely fundamental way all our inherited philosophical concepts, categories, and basic presuppositions. Nothing like this has happened since Parmenides. [9]

I will try to justify and clarify this appraisal in this chapter and throughout the book.

Of course, the fear of the unknown is very powerful, and, no doubt, one can *always* find a justification for continuing with the millennia-tested numeric—or, appealing to the useful astronomical metaphor, epicycle-like—sorcery. After all, it has brought us (truly miraculously) thus far, hasn't it? Yes, indeed, this purely calculational attitude has 'produced' much more than one could have expected, and we should be thankful for that, but presently it has outlived its usefulness, and I do hope that some of us, especially those who feel more acutely the present disharmony in science (and society), are brave enough to keep our eyes wide open to the possibility or even necessity of the above radical conceptual change.

So I do believe that we are poised to shift from the ubiquitous numeric representation—which has outlived its usefulness as the *main form of object representation and* which entrenched the mind-matter split—to the structural representation (and the associated structural measurement processes), which should eliminate this split. The next section points to the problem whose satisfactory solution I believe to be the key to this elimination.

3. Original motivation for the development of the new formalism

The new representational formalism—whose technical (and possibly outdated) name is *evolving transformations system*, or **ETS**—was motivated by the problem of induction, the problem that has plagued both philosophy and science for over two thousand years. So it is only fair to begin the book proper, in the next chapter, with a brief history of this ubiquitous problem. Here, however, I wish to suggest that, despite its controversial status, the inductive process *is* the key to understanding the nature of biological information processing, and hence the nature of information processing in the Universe. Indeed, there are many reasons to believe that the *basic underlying* information processing system is the same for all biological organisms, and moreover, without any template in Nature such a powerful system could not have emerged during the biological evolution. Biological evolution *can* provide new 'engineering' or 'architectural', including various 'hardware', solutions (for example, for the development of the eye) but not a *fundamentally* new information processing systems, since the latter—because of its indivisibility—simply *cannot emerge incrementally*. As I discuss in this book, there can be *just one basic* information processing paradigm in the Universe.

The all-pervasive problem of **induction** is briefly this: How do we learn what a 'cat' is after seeing just several cats? You may not realize that, previously, we have hardly moved at all toward solving or even understanding this deceptively familiar problem. And this is despite many centuries of attempts by our greatest philosophers and the sustained scientific and commercial efforts of tens of thousands of post-World War II researchers and engineers from many disciplines both at universities as well as various, including wide varieties of military, companies throughout the world. For example, you may not know that Google and Microsoft have many researchers working on it (you will see why in the next chapter and Chapter 11). So what are the difficulties?

First of all, we should agree that 'the class of cats' exists: if it does not exist, we would not be able to recognize the previously unseen cats. Then, *what* is this thing we call "the class of cats"? Is it associated with some 'intrinsic' structure of a cat? *Where* does this class exist? Does it exist in our minds *only*? What is the connection between a particular cat and the class of cats? Second, if the class of cats exists outside our minds, as biology suggests, do "the class of stars similar to our Sun" and "the class of hydrogen atoms" also exist? (We know that these classes have existed for longer periods of time than the class of cats.) In general, the concept of **class**—of similar objects or processes—is one of the central concepts in this book, which in this, introductory, chapter I use relying on your intuition. 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* (see below)—*structure*. 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*. As I discuss throughout the book, it appears that *the way* the mind, and hence Nature herself, 'decomposes' and 'represents' a cat is based on this formative structure. Our minds, obviously, do not have access to all the details that Nature has, but the *overall* structure, or the form, of the decomposition of a cat—*its representation*—must have been *adopted from Nature*, since, again, the basic informational structure itself cannot evolve.

I believe that the persisting misunderstanding of the induction problem is related to *the inherent inability of both human languages and the numeric formalism to deal with this, formative, structure—and as a result with the concept of class—adequately*. It appears that the uniqueness of the induction problem—and its proposed *strategic role in the development of information processing and hence all of science*—have to do precisely with its (not obvious) inherent need for this *much richer form of data representation* than has been historically the case in science.

The unsuitability of human languages for this purpose should not come as a surprise, since the mechanism responsible for induction is of perceptual origin. Yet it is the reliance on our language as the medium that has caused the millennia old—and still fully persisting today—*fundamental misconceptions about induction*, including the application of induction to the cases where its applicability is meaningless. This is the case when *the set of objects involved is not a class*, i.e. their formative histories are not similar, hence no *structural* 'glue' that binds them together. For example, to use induction to characterize all readers of a particular book is a meaningless undertaking, as this set is simply not a class: almost anyone can be such reader. Another persistent misconception about induction comes from a (quite typical) situation when one has been exposed to a sample from a *subclass* of some target class—for example, you have seen only white swans—but *assumes* that the sample reasonably represents the *entire target class*; then you are, of course, liable to make wrong conclusions about the target class—e.g. that *all* swans are white—and the induction should not be blamed for your conclusions. Also note that the reason why the basic mathematical induction does not require us to take similar precautions before applying it, has to do with an extremely simple class—the class of natural numbers—over which this induction is carried out (see this section below). Thus, again, it is the inaccessibility of a satisfactory concept of class within our spoken languages as well as within the numeric formalism that have been the main source of misconceptions about induction.

However, despite the various controversies, as Bertrand Russell suggests, it is important to accept *the pivotal role of induction in information processing* (see also the epigraphs to the next chapter):

> Induction raises perhaps the most difficult problem in the whole theory of knowledge. Every scientific law is established by its means, and yet it is difficult to see why we should believe it to be a valid logical process. . . . When mankind took to science, they tried to formulate logical principles justifying this kind of inference. . . . I will only say that they [the results] seem to me very unsuccessful. I am convinced that induction must have validity of some kind in some degree, but the problem of showing how or why it can be valid remains unsolved. Until it is solved, the rational man will doubt whether his food will nourish him, and whether the sun will rise tomorrow.[10]

Our central natural science, physics, has not and could not have been concerned with the above questions. Modern physics grew out of the questions surrounding the *motion* of various bodies *in space* (Chap. 5), which are not related *in an obvious manner* to the concept of class, with the latter being much more 'informational' concept. Regrettably, computer science has also not addressed this concept (Chap. 11) [11], even though during the last decade or so it became more fashionable for computer science departments to hire people that are working in the related areas. So far, induction has been mainly addressed, though quite unsatisfactorily, besides philosophers, by engineers, statisticians, cognitive scientists, and some others. Since the problem of induction does not fit into *any* of the developed scientific directions, the above researchers could not have been 'trained' to approach it as a fundamentally new 'natural science' problem, but with an informational bent, as I treat it in this book. And most interestingly, it appears that to approach this problem appropriately requires us—for the first time in the entire history of science—to change radically the basic scientific language. While the numeric representations of objects and processes in our present mathematics—and hence physics—are point-based, it appears we need to *replace this ubiquitous 'point'* (of geometric, or spatial, origin) with an appropriate universal *structure* that must also become ubiquitous, thus leading to the new, 'structural', mathematics. So it seems that the main difficulty has to do with the unprecedented need for a *new kind of mathematics*.

4. The basic idea of the proposed structural representation

During my career as a computer science professor working in the area of pattern recognition, it has gradually become clear to me that to address the concept of class (of objects) one needs to develop a fundamentally new *representational* formalism, capable of capturing the above concept of structural data representation. As we look at Nature, anything we see has a particular structure, and *all objects from the same class have similar structure*. How can we capture this concept of formative structure? Trained as a professional mathematician, initially, I was completely unprepared for the possibility that

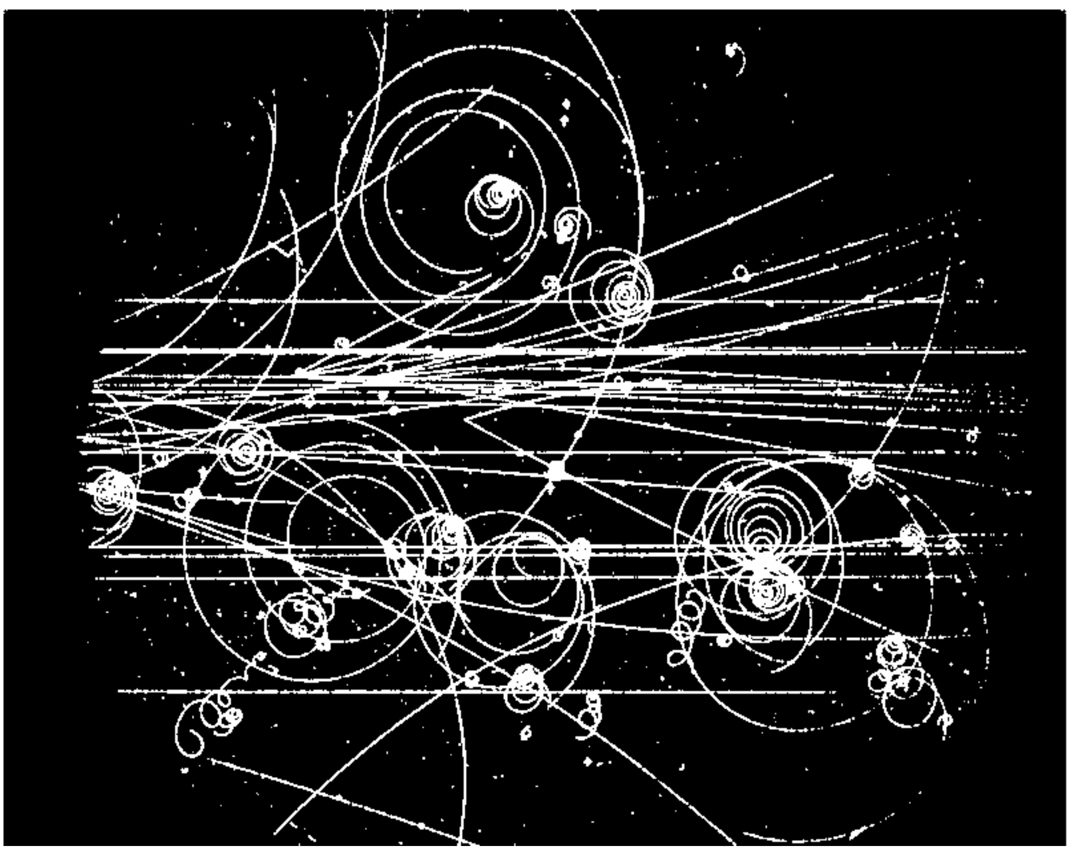


Figure 1.3: Each line, or track, in this bubble chamber photo of the particle beam (coming in from the left) is actually composed of a sequence of *events*, most of which we can hardly see, but, as is well known, they are there.

http://cdsweb.cern.ch/record/842723/files/lhc-pho-1999-258.jpg the present mathematics may not have *any* satisfactory mathematical structure within which one can model the inductive process. But eventually it became clear to me that the relevant object structure—and so the very concept of class—cannot be adequately approached relying on the conventional mathematical structures. This is because, again, all conventional mathematical structures have evolved based on the numeric, or *'point'*, representation of reality, which is of spatial origin, and hence none of them can accommodate adequately either the structural view of reality or the sought formative object structure, which are of *temporal* origin.

Eventually, we were lead to assume—as Heraclites, Hegel, Bergson, Russell, Whitehead and others have suspected—that any object, or process, in Nature *should be viewed and represented as the temporal stream of interconnected events that compose it* (Fig. 1.5). Obviously, such streams overlap. In fact, as we already know from particle physics, all elementary processes *are* streams of events of *various* 'structure', as can be gleaned from Figure 1.3, where more conspicuous events are junctions each transforming the pattern of flow of several processes. So if we generalize and formalize this intuitive picture, we arrive at the basic idea of the structural formalism proposed by us.[12]

The basic concept of the formalism is that of the *informational event*, which is a (structured) *junction transforming the flow of one or several incoming 'elementary information processes' into the outgoing ones* (Fig. 1.5).

According to the universally accepted in mathematics axiomatic view of natural numbers (discussed later in the book), the natural number itself can also be viewed as a particular stream of *identical events* shown in Figure 1.4, where each event simply 'regenerates' the incoming elementary process. And so, in this case, we are dealing with a *completely homogeneous overall process*, i.e. not involving *structurally different events*. Therefore, it is not reasonable at all to expect such *homogeneous* representation medium as numeric to be suitable for capturing various *structural relations* among structurally *different kinds* of events (Fig. 1.5) pervading our *evolving* Universe. Indeed, object's mass, volume, or energy, to take some examples, convey hardly any information about the object's structure, i.e. its *formative structure, which is what the structural representation should all be about.* It is in this, important, sense that numbers are less 'real' than the *structs* (Fig. 1.5), which we describe next.

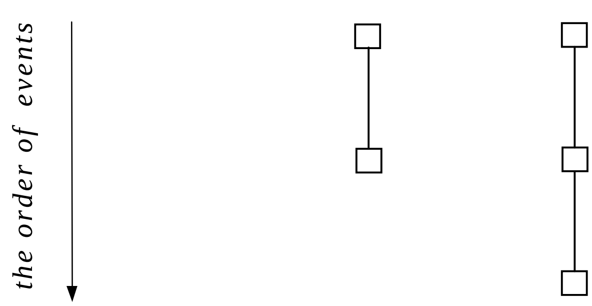


Figure 1.4: The *proper*—both formally and historically—representation of numbers 2 and 3 should be understood as a *temporal* construction involving the consecutive application of the *same operation, or event,* depicted as a square. (The number of processes that are coming in and out of such event is not of essence, as long as all *events are identical and each can be attached only to the one immediately preceding it*.)

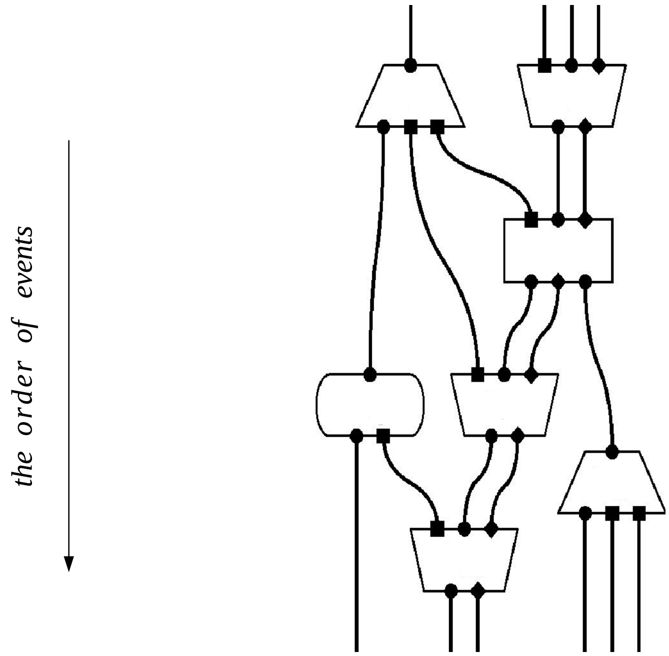


Figure 1.5: *Pictorial depiction* of a (very short) **struct**. Each larger shape depicts a particular kind of **event**; there are four kinds of events. Also note three kinds of links (coming in and out of an event), where each kind is designated by a small *solid shape*: each link must begin and end as the same kind and, as a visual aid, may be marked by a fixed color. All events and their links are 'informational'.

Returning to Figure 1.1, to contrast the numeric representation with a structural one and to give you the flavor of what is to come, Figure 1.5 shows, with minimal explanation, an example of a **struct**—a proposed far-reaching *structural generalization of the natural number*, i.e. a *fundamentally new, event-based, form of data representation*. As was mentioned above in this section, a struct is a temporal stream of interconnected structured **events** of purely *informational* nature. Hence the events are understood *outside any spatial context, as possible blueprints for the spatially realized entities which we observe*, e.g. as in Figure 1.3 or when we hear a musical segment. In connection with the last example (musical segment), it is useful to keep in mind that auditory perception gives us a *more direct* access to the relevant temporal structures than, for example, a much more complex visual perception, which of course, should rely on the same structures. As to Figure 1.5, one should not confuse the pictorial depiction of a struct with the actual concept, which can be defined formally. Again, an important point to remember is that the struct is not a spatial concept: both the events and their interconnections are not of spatial origin, and in this particular version of ETS we are faced with the separation of temporality from spatiality. The structure of each **event** is associated with the kind of reorganization, or *transformation*, it carries out when the incoming 'processes' are *transformed* into the outgoing ones. (In the special case when the incoming and outgoing processes coincide, the transformation can be thought of as 'regeneration'.)

Since the struct is an informational concept, I will use the term '*instantiation*' when referring to its *spatial realization* based on the blueprint provided by it, which is more accessible to us (see also Section 1.6). Keeping in mind that the formation and evolution of *any* object in Nature is associated with the temporal stream of the corresponding events, *to visualize the instantiation of a single event*, picture an object/process being transformed according to the information contained in that event. And since *all* processes in Nature are composed of events, examples (of instantiations) of the above events comprise *everything* around us: all events in particle physics, all events in chemical reactions, any event in the development of an embryo, etc. (For the initial *illustrative* example, see Sect. 2.9.) The crucial hypothesis here is that *the proposed or similar structure of events is universal in Nature*.

For those who are familiar with various historical generalizations of the real numbers—i.e. complex numbers, quaternions, and octonions—note that the above structural generalization of the natural number has hardly anything to do with those generalizations, which are just multi-dimensional 'versions' of real numbers. The critical difference is the incorporation of the structured events.

So the struct is a completely new kind of, *temporal*, generalization of natural numbers, and it also embodies the concept of *discrete*, as opposed to continuous, representation, which is supposed to clarify the discrete nature of physical reality, including the 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. . . . Finally, transmutations—the modern analogue of the Aristotelians 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 [the great Soviet physicist] suggested *viewing a particle's motion as a series of regenerations: transformations of this particle into a different particle and the subsequent reverse transformations into the original particle*. [My italics] [13]

As will be briefly discussed in this chapter and, in greater detail, later on in the book, *the source* of such (regenerative) motion cannot be located in space itself, at least as the space has been understood so far, so that, again, the struct appears to be of non-spatial origin.

Returning to Figure 1.2, we can now intuit better why the introduction of struct may mark the beginning of a fundamentally new scientific tradition.

Interestingly enough, already in 1948, Bertrand Russell devoted a substantial part of his five hundred page book *Human Knowledge: Its Scope and Limits* "to suggest the analysis of physical entities into structures of events, and *even events, as I* [he] *shall try to show, may be regarded with advantage as having a structure*" (p. 250, my italics).

Thus, as has been suspected by many [14], the postulated basic informational unit of 'reality' as well as the representational unit is the structured event. I believe that this should *harmonize* our scientific perception of reality with our sensory perception, when *both rely on the events (while so far the science has relied on the numeric features)*. Of course, the structure of the basic physical events comprising the processes currently called "elementary particle" is the immediate task before experimental physicists. At the same time, as will be discussed in Chapter 17, since ETS formalism eliminates the present pyramid of sciences with physics—specifically particle physics—at the bottom, the work in practically all fields, including much of physics, *can* proceed independent of the latter experimental work, relying on the proposed general 'language' of events. The future modifications can then proceed incrementally, without any fundamental change in the *basic form* of the underlying representation. Also, while the number of initial, or elementary, events in Nature is expected to be quite small, as we will discuss in Chapter 15, *at each new representational stage* there emerge new (macro-)events, whose overall structure conforms to the above hypothesis but each of which stands for the previous stage struct segment.

One should also keep in mind that since the structure of the event is related to the kind of the transformation it accomplishes, this structure is mainly related to the *types* of the incoming and outgoing processes. Most importantly, in the proposed formalism, the *formative object structure*—both in Nature and in the mind—is represented by the corresponding struct and so emerges (temporally) as the overall global pattern of the interconnected events. To put it differently, the struct is, simultaneously, the *blueprint* for, and the *record* of, the development of the corresponding object. This is the key to understanding the nature and the role of the proposed structural representation.

Throughout the book, I will discuss why the struct, for the first time, offers the long thought for, for example in biology, form of data representation that explicates the concept of 'formative object structure', but applicable not just to biological organisms but to all objects in Nature.

Note that a struct evolves when the appropriate new events—that are "attached" at the bottom of the struct—occur. Sometimes, some of the *incoming* links in the latest event may happen to be connected to the outgoing links of some bottom events that have occurred much earlier (if the corresponding links coming *out* of those earlier events were 'free'). This explains how a present event may reach far into the past. An archeological finding or a light reaching us from a distant galaxy are such examples.

Again, one should keep in mind that an 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 analogy will become more apparent in Chapters 14 and 15, when we introduce different "levels" for both structs and events, so that *before* the above *basic* events appear, there appear higher level undifferentiated entities which later become differentiated into these basic events.

Thus, Figures 1.4 and 1.5 depict *two different versions of* s_i in Figure 1.1, one being a *proper*—i.e. *temporal*—structural generalization of the other. However, *while the numeric representation can be collapsed into a point (via counting), the struct cannot be collapsed to a number or even several of them without loosing most of its structural, or relational, information*, including the events' interconnections and the *types* of the incoming and outgoing processes. The introduction of complex numbers, matrices, etc. does not essentially change the situation in this respect, as will be discussed in Chapter 7: adding more numbers cannot substitute for the above temporal structure. Moreover, I will argue that the proliferation of various numeric aggregates in mathematics is not reflective of a much simpler organization of Nature, but rather can be explained by the semiconscious attempts to find numeric substitutes for the structural representation.

Comparing Figures 1.4 and 1.5, one can also easily see how the very origin of our collective scientific journey—the *temporal* concept of natural number—was relied upon as a springboard for its *temporal* generalization, i.e. how the *single* event, out of which a number is built (Fig. 1.4), is replaced by *several structurally different* events. The same comparison can suggest the radical shift in emphasis, from counting to the (temporal) formative structure. Above all, *the information recorded about each object in Nature by the corresponding struct is fundamentally different compared to that captured by the numeric representation*, so that we now 'see' a real object in a completely new 'light'.

It is useful to note that, as will be discussed in Chapter 3, the collapsed and more *convenient* form of a natural number, e.g. symbol *2*, has emerged historically simultaneously with the development of writing, and it is this convenient form, soon followed by various measurement practices, that have contributed to our *non-temporal*, *or non-structural*, perception of numbers. Of course, today, at the onset of the information processing age, we should no longer be guided by the *same* convenience considerations as we were at the onset of writing, 4–5 millennia ago. And, again, as far as all sciences are concerned, the adoption of the new form of data representation, the struct, would signify a radical shift from the reliance on the *indirect*—numeric and spatial (i.e. in some abstract space)—*data patterns* to the *intrinsic, relational and temporal,* i.e. truly structural, patterns each of which represents the formative object structure.

Most importantly, the replacement of "points", "lines", and "surfaces" by "events" and "structs" cannot be overestimated for the future of science: if the universality of structured events in Nature will be 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 events of similar structure, which cannot be said of points, lines, and surfaces!

Returning to the problem of induction, as mentioned above and will also be discussed in the next chapter, the main point is that an adequate concept of class (of similar objects) cannot be adequately introduced within the numeric representation. This is because the proposed *concept of class depends critically on the formative object structure.* So if the formative information *is not explicitly present in the data representation*—the case of numeric representation—we end up with an *unbridgeable gap* between the class and its members: in this case there is no reliable way of getting from the set of class examples to the class description, where the latter depends critically on the formative information not present in the data. I suggest that the seemingly insurmountable difficulties encountered so far in addressing the problem of induction have to do exactly with this state of affairs. Again, the connection between the concept of structural representation and that of class is critical here: *unless the representation can support the appropriate, i.e. formative, object structure, a satisfactory concept of class simply cannot be introduced within it.* This is also the key to understanding why induction should play the strategic, or catalyzing, role in the new development of science.

How does the struct capture the formative object structure? As already mentioned above, if we were to see a visual, or *spatial*, simulation of what happens as the events in the struct unfold, we would see an abstract version of a 'developing embryo': how, starting from naught, there appears the initial undifferentiated blob which gradually, as events unfold, becomes differentiated further and further until, finally, the corresponding object itself appears [15] (see also Sect. 2.9).

The burgeoning fields of pattern recognition, machine learning, and data mining—which deal with theoretical and applied issues related to induction—have proceeded with the development of both the statistical theory and the commercial software for classification (including such companies as Microsoft and Google) without the benefits of the concept of class available to them. So, ironically, *one is doing classification without knowing what a class is*! No wonder all developed programs are quite 'brittle', i.e. minor changes in the input data may produce quite unexpected results, and what is more, in contrast to the wide-ranging knowledge gained by a human as the *result* of classification, there are hardly any additional benefits of the above software.

Thus, one of the main reasons why we settled on the above ETS formalism has to do with its *intrinsic* capability to accommodate a sensible concept of class and, as we expect, to ensure the solution of the inductive problem, i.e. 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 to expect the resolution of the millennia old problem of induction?

The basic reason is, in some sense, quite apparent. First, the new representation, i.e. the struct, contains *much more relevant information* about the object it represents than any known representation. And second, more importantly, this information is directly relevant to the recovery of the corresponding class: according to the definition of class adopted in ETS (see the next section), *all objects from the same class have 'similar' formative histories* and each of those *is recorded explicitly in the corresponding struct*. So the secret of the proposed structural representation is that there is no secret at all: it's all in the structural representation. For example, it is natural to expect that several 'cat' structs should provide enough information for the recovery of the structure of the class of cats. In other words, if we have the formative structures of 15–20 cats in the form of the corresponding structs, we can then extract the appropriate 'pieces' and the ways they are put together to extrapolate to the structure of the entire class of cats, since—by definition—all cats have similar formative structures. Here, the "cat's struct", as will be briefly discussed in Section 6, refers to an *agent's representation of the cat*, which should not be confused with another, more complete, struct representation of the same cat *in Nature*.

(One might be tempted to cheat and try to encode numerically the above structural information, but then such numeric encoding would not be of much use, since, first, the numeric measurement devices would be unable to get this information, and second, one would need to continue to copy all the relevant mathematics of structs.)

Lastly, as was intimated above and stated in the following (first) postulate, the new form of representation appears to be universal, i.e. meeting the needs of *all* sciences.

5. Informational organization of Nature

Here are the two main hypotheses, or postulates, regarding the informational (and *underlying*) structure of Nature. They are the first of this kind—i.e. explicitly addressing this informational structure—and they, particularly the first one, lie at the very foundation of the proposed structural formalism. They also suggest how one should interpret 'information' and 'information processing'.

1. The first one is concerned with *the primary structure of all processes in Nature*: the *underlying* structure of each process is the informational stream of the interconnected structured events (see Fig. 1.5).

2. The second one is concerned with *the underlying organization of Nature*: evolving and interacting *classes* of processes form the primary, informational, organization of the Universe, where each class is specified by its class representation.

The central concept of **class representation** [16]—without which the concept of class (of objects) appears to be not meaningful—will be addresses in several later chapters but for now it can be thought of as containing *an informational 'recipe', or algorithm, for constructing the representation of each, presently possible, class member* (Fig. 1.6). The 'recipe' is a *stepwise* specification for constructing

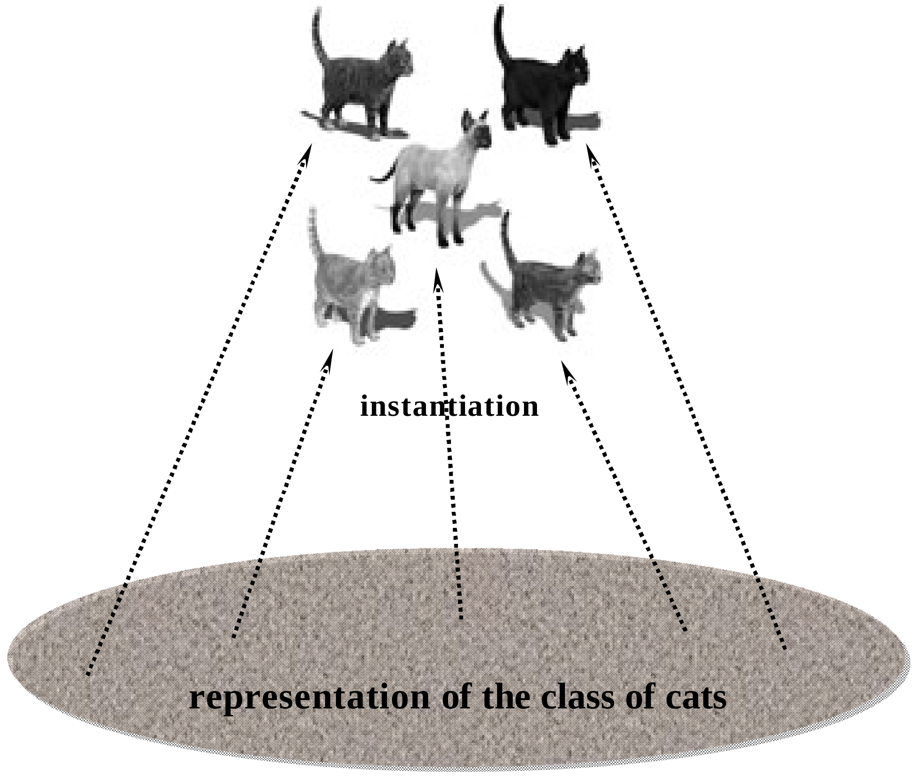


Figure 1.6: The concept of class representation, including its primary role in the instantiation of the class objects. Each arrow should not be interpreted as coming out of a particular location but as dependant on the entire class representation.

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

the struct for any class element *possible at this time*. In particular, associated with each such step is the set of structural *constraints* restricting the kinds of struct segments admissible at this step in the construction. This means that any struct segment satisfying one of the constraints can be applied at this step, provided, of course, it *can* be attached to the struct that is being constructed. (As you can readily check, not any struct segment can be attached to a given struct: the appropriate connecting links must match.) It is important to mention that these constraints are such that they do not forbid *some* 'environmental', or 'external', struct segments to participate constructively in this generating process: in that case such segments become part of the resulting struct. So the interaction with the environment, i.e. with other classes in the environment, becomes possible.

It is also important to keep in mind, first, that, as objects themselves, 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. And second, for a reasonably evolved Universe, for most classes, the class representation is capable of 'producing' an enormous number of possible (different) class members.

For lack of a better idiom, the class representation can be thought of as the evolving 'DNA' of a class, but the reason that DNA is not a satisfactory metaphor has to do with the above second hypotheses: the actual DNA is 'hardware' part of the corresponding class representation, since the class representation, being an informational concept, *cannot be reduced to the hardware alone*. A somewhat closer but less known and less understood metaphor—coming from developmental biology (and more popular in the first half of the last century)—is that of the morphogenetic, or organizing, field. This field is associated with the group of cells forming a particular (future) organ, e.g. an eye, hart, or forelimb, and is supposed to guide their *specific* developmental process even when the group is transplanted to a different part of the embryo.[17]

At the same time, the concept of class representation should offer a better insight into how the DNA itself should be viewed: it is a more visible *part* of the class representation mechanism. As to how a class representation might be stored in Nature as well as how its two-way relationship with a particular class member is implemented are related and presently non-trivial issues—which will have to be addressed in a novel experimental setting—although as I suggest in the next section it is quite possible that such informational/temporal representation is not 'located' in space but 'outside' it. (In connection with the latter questions, I can't help mentioning that if, in an apparently much more clearly delineated case of gravity, we have been, and are still, waiting for the detection of the graviton—the particle which mediates the gravity force—for so many decades, we should have enough wisdom to wait for a while until we get more answers to those questions.)

Note that the concept of class is *defined* via the concept of class representation: no class representation, no class. This constitutes the main difference between the conventional and the proposed approaches. Of course, such view of the concept of class becomes possible only under the structural representation: within a numeric representation the above concept of class representation cannot arise.

Regarding the second of the above informational postulates, I should note that it is fully consistent with *the origin of the term 'information'*: by 'in-forming' someone we would like to 'transmit' the relevant 'Forms' (structures of the classes) in the sense of Plato and Aristotle. So the proposed view of Nature can be seen as a return to the informational and evolutionary version of the 'Forms' of Plato and Aristotle. In this connection, it is useful to keep in mind that *the most appropriate modern meaning of the relevant ancient Greek "eidos" (Form) is "structure"*.

Both of the above hypotheses can be gradually verified. The second one also points to the classes as responsible for the persistence of patterns in Nature: whenever a process appears, it does so as a member of the corresponding class of processes, obeying its structure, be it even the very first member of the class. If this postulate were not true, the Universe would have been completely chaotic, hence unpredictable: every time several particular processes interact, we would not see *qualitatively* stable outcome and so no regularity in Nature. Such informational explanation of the observed regularity in Nature is much more satisfactory, or less artificial, compared to the conventional, law-based, scientific picture, where the equation-based laws appear out of nowhere: these laws are not a *natural part* of the Universe. Moreover, the existence of classes and their representations would explain, for the first time, the fundamental reason for *the prevalence of the constructive, or formative, processes in nature—in contrast to destructive ones* (the second law of thermodynamics)—as has been suggested by a number of scientists and philosophers.[18]

As far as the *underlying orientation* of physics—and, as a consequence, of all natural sciences—is concerned, the last point (also addressed in Chapters 8 and 9) is impossible to overestimate. Indeed, our science has evolved based on the reductionist principle, which is *of spatial origin*: to understand the nature of things seek their parts and assume that they are more fundamental than the wholes, since 'obviously' the whole is just the sum of the parts. For example, in physics, everything is reduced to the *elementary* particles, in chemistry, to atoms, in biology, to genes. Accordingly, physicists seek the unified theory at the evolutionary level when all *structures have not yet been present* (the Big Bang). However, since the Universe, as we observe it, consists of various structured entities *at all levels that we can perceive,* from the minute building blocks to the vast stretches of cosmos, it is much more likely that the key has to be sought exactly in the opposite direction, i.e. in understanding the ubiquitous *formative, or structuring, laws* of nature. Of course, such scientific reversal could not have been undertaken without an appropriate structural representation. The above 'obviousness' of the reductionist principle comes from our spatial (rather than temporal) experience: things can 'easily' be decomposed and recomposed. Yet, in the informational—as opposed to 'architectural'—realm this principle brakes down, since the flow of events cannot be reversed.

As to the starting point, the above two informational postulates suggest that in the beginning was neither the "Word", as mentioned in the Bible, nor the "Deed", as suggested by Goethe's Dr. Faust, but was the "Event", which was the informational *blueprint* for the corresponding *spatial* event that followed.

Again, I wish to draw your attention to the above, completely new and *important, feature in the structure of the proposed formalism*: in contrast to the more 'promiscuous' numeric formalism, it directly postulates the structure of reality in the form of the two basic hypotheses. These initial hypotheses, on the one hand, make the formalism relatively easier to falsify, and on the other hand, if they will stand the test of time, we will not need to speculate as much as we do now about the nature of reality. Both consequences are quite desirable: the explicit declaration of the basic informational structure of the Universe offers new, critical, falsifiability criterion for the proposed formalism. For example, the discovery of the process that *cannot* belong to any class (admittedly not an easy task) or of an event whose structure is inconsistent with the proposed one would falsify the formalism.

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

In particular, it is quite telling that in order to account for the existence of life in the Universe—which requires a delicate 'fine tuning' of the present physical laws—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".[19] Of course, the proposed 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 above perspective suggests the primacy of the informational reality, it stretches credulity to a much lesser extent than the conventional perspective does. The latter requires the instantaneous appearance of the Universe (in the form of its mass/energy) together with *the numeric laws that govern it* (in the form of equations).

Regrettably, computer science has only been concerned with *computation* and has very little to say about the above or any other ‘natural science’ view of information processing. If anything, computer science has substantially contributed to a pervasive simplistic, computational, view of information processing in the Universe in general, and in physics and biology in particular. As we will discuss in Chapter 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 [20], and this situation has played a decisive role in isolating computer science from the agenda of the natural sciences. No wonder that in a (futile) attempt to change this situation some leading universities are trying to move their computer science departments to science faculties. Even the recent developments such as bioinformatics and cheminformatics—initiated mainly by the researchers 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 completely consistent with the foundational structure of computer science.

The area of quantum computing has also not contributed appreciably to our view of the informational organization of the Universe, despite some of the claims to the contrary, including the misleading, but consistent with computer science, idea of “programming the universe”.[21] This is because this new area focuses, again, on the computation and the engineering aspects of quantum mechanics. However, quantum mechanics itself—*due to the its fundamental reliance on the observer and the related unresolved very basic issue of what constitute a measurement*[22]—would benefit from the development of an appropriate information processing model: the role of the observer, or the mind, has been increasingly coming into prominence from the very beginning of this field. And more importantly, as will be discussed in Chapter 8, quantum mechanics, which deals with the *discrete* phenomena, is relying on the *continuous* formalism simply because our present mathematics cannot offer any relevant (discrete) representation.[23]

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

Such unexpected consequence of the Scientific Revolution *would have never been anticipated* by its founding fathers: 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 main heroes of this revolution. Such fundamental confusion, by itself, is another telling sign of the urgent need to deal with the present split between the physical and the mental (mentioned in Section 2), *which is now seriously impeding our progress in all information processing fields, and hence in all sciences*.

Nevertheless, one unexpected exception should be mentioned. There is an important area of cognitive science, *linguistics*, whose development points in the same general information processing direction I am advocating. The founding father of modern linguistics Noam Chomsky, from the very beginning of his work in the late 1950s, has been emphasizing the critical importance of 'generativity' both in linguistics and in the organization of the mind in general. The idea of generativity, as proposed by Chomsky, has to do with the scheme, now extensively developed, that the *syntax* of any sentence in any language should be viewed in terms of some (abstract) *generative grammar*. Such grammar consists of a list of *production, or substitution, rules*, written in the form $A \rightarrow B$, where A and B are some abstract strings of symbols. Such rule signifies that wherever string A occurs—either by itself or as a substring—one *is allowed* to (but does not have to) replace it by B. Such 'generative' rules, when applied successively, can be used to generate any sentence, starting from a very simple production rule. For example, suppose we have three rules: $S \rightarrow NV$, $N \rightarrow$ "the man", $V \rightarrow$ "danced" (S is for the *start symbol*, N is for *noun phrase*, and V is for *verb*). We can now generate the sentence "the man danced" in three steps: $S \rightarrow NV \rightarrow$ "the man"$V \rightarrow$ "the man danced".[24]

Thus, in *some sense*, the idea of grammatical generativity and generative structure, to which we will return in Chapter 12, is similar to the above idea of formative structure but with two *critical* differences. First, no one in linguistics or in cognitive science in general, realized that in order to be able to take the full advantage of this idea, one would need to introduce a fundamentally new concept of structural representation, as discussed above. After all, a string itself, although a richer form of representation than a number, still missing critical information about its formative history, i.e. *how it was formed*, or generated. And second, the main reason behind the generativity must be thought not in language but rather in the much more basic informational structure that the development of language *simply had to rely on*. So the important lesson one can draw from the development of linguistics is this: since there are an *unlimited* number of grammatically correct sentences, which therefore cannot all be memorized, Chomsky tells us that *there is a clear need for the mechanism that is capable of and responsible for generating such sentences whenever the need arises*. But instead of postulating the genetically innate "universal grammar", as Chomsky does (see the last reference), I am proposing a much more universal—not specific to humans or even biological organisms—informational mechanism of class representation that relies critically on the structural, or formative, object representation.

As to the topic of "consciousness" in the Universe and its relation to various classes, I do not intend to discuss this issue in the book simply because it is just *too early* to talk about such entity, if it exists. 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 the Aristotelian 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 issues.

In this connection, I also believe that the present scientific escapades into the origin of the Universe are premature, mainly because, as will be discussed in the book, our present *concept of matter* and the associated *formal apparatus of differential equations* are quite inadequate (and were not indented) to address the question of origin. This inadequacy also manifests itself in an increasing number of the proposed *non-physical* principles that have proliferated physics and astronomy during the last half a century (see this section above).

Looking into the near future, one simple but important point should be made. As was the case with the numeric representation, *we need to learn how to see the world through the spectacles* of the proposed structural representation. This representation is a big step into the unknown, and we cannot know right away if we land exactly in the right place. We can find this out only after the representation has been extensively battle-tested in various scientific and technological applications. However, in this book, I hope to convince you that we do need fundamentally new, structural, forms of representation that bring in the class-oriented, or generative, view of *all—and not just biological—* objects in Nature. As will be apparent already from the example in Section 2.9, while within the conventional view objects are perceived as more immutable, possessing fixed features (recorded numerically), under the structural view, *all objects* are assumed to be the results of class-related generative, or *formative,* processes, which, as information processes, are hidden from the conventional view of reality. Yet if the proposed view is on the right track, then *no, including any future, analytical machinery in the numeric setting* is capable of the miracle of producing *the information that was not present in the original data in the first place*.

To summarize, I propose to identify *information* processes in nature with the *formative* ones, i.e. with those ubiquitous processes that are responsible for the construction and maintenance of *all* classes of objects in the Universe. As will be discussed in Chapter 11, I am not the first to suggest the basic role of classes in nature. Obviously, so far, no science has undertaken the development of this view, which, I believe, has been mainly due to the lack of the appropriate form of data representation.

As to the concept of information process, I recently found the following, related, characterization of an information process by a Soviet philosopher:

> Hence the information process can be defined as a free movement of an invariant structure in the material carriers of various nature, and the information can then be thought of as this invariant structure circulating through the communication channels. [25]

6. Structural time and other remarkable features of the new formalism

Based on the development of the scheme originally set in motion by the Scientific Revolution, a number of physicists are now contending—no doubt to the horror and consternation of the principal heroes of this revolution—that time is simply an illusion, and we live in the timeless Universe.[26] Such claims are not based on any fundamentally new discoveries and are quite meaningful within the numeric formalism, since all basic equations of physics are insensitive to the direction of time: this is a simple consequence of treating time as an extra 'spatial' dimension. But such claims have woken up a number of other physicists to the fact that, perhaps, not all is well in the kingdom of physics, and the starkness of the claims have drawn a renewed attention to the old simmering issue of time and its role in physics.

As a result, besides the well known—but, in my opinion, not sufficiently radical—quest to rehabilitate the time in science by the late Ilya Prigogine [27], a number of physicists have begun to realize "that we are far from having a good grasp of the concept of time" [28], 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." [29]

As you might have expected, I do agree with this comment by Lee Smolin that *all* solutions proposed so far to address the issue of time do not aim deeply enough. And indeed, how could they? I mentioned it above and will argue in the first half of the book that the issue of time cannot be addressed adequately within the numeric formalism. In other words, time cannot be understood in a spatial setting—i.e. as an extra dimension or even several of them—which can only lead to such unnatural concepts as an instantaneous state of a system. As Whitehead and others have emphasized, "there is no Nature at an instant": in Chapter 7, we will discuss the obvious fact that *any spatial event* in Nature takes some time, albeit very small, to happen, so a truly instantaneous slice does not speak to the physical reality and such, basically, formal concept *could have been motivated only by its spatial analog*, for which it is more meaningful. In this respect, the best available treatment of time in special relativity theory, via Minkowski 4-dimensional space-time, is only a relatively small improvement on the classical treatment. It appears that *time should not be adjoined to space in any shape or form*: since time is a qualitatively different entity embedded in the flow of (informational) events, the framework for time must be sought outside that for space. I believe that the inability to address the concept of time adequately is the single most important issue which will be responsible for the reconstruction of physics on a new basis.

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

Thus, the illusive irreversibility becomes now a simple consequence of the fact that none of the events can be undone. Moreover, when all of the events are identical and each is connected to the immediately following event only, we get a very simple, 'linear' flow of events corresponding to a natural number. Otherwise, for practically all processes in Nature, we are left with the entirely new, 'non-linear' or structural, idea of time. So, again, the new view of time emerges as a far-reaching generalization of the temporal interpretation of natural numbers, and hence of the conventional, or 'linear', concept of time, where the latter, via the real numbers, led to the identification of time in physics with the extra dimension.

What can we say about the emerging concept of space? Here the situation is somewhat less definite, since there are at least two options. However, *if we assume the precedence of temporal, or informational, structure over the spatial*—as has been urged by a number of philosophers, see Chapter 17—than, obviously, all spatial structures should emerge based on the information contained in the corresponding structural representation. For example, to construct, or instantiate, *the spatial structure corresponding to a struct*, one needs to interpret the relational information in a struct, i.e. the links between the events, as the neighborhood information between *the spatial regions corresponding to the events*.

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 precedence of temporal representation over the spatial. In general, it appears that our auditory perception can give us a more immediate appreciation of that precedence than a much *more complex* visual perception, which, although it also operates temporally, must rely on the spatial instantiations of objects.

Interestingly enough, as will be discussed in Chapter 17, the above precedence is in line with several other recent proposals by a number of physicists working in quantum gravity, who also suggest that the space might be generated by some more basic discrete structures.[30]

Quantum entanglement provides some evidence supporting such separation of the informational and spatial representations: the presently hypothesized practically infinite speed of ‘communication’ between several entangled particles strongly suggests that the information between them does not pass *in space*.[31] Moreover, the “uncertainty” that was famously introduced in quantum mechanics and claimed to be ubiquitous may turn out to be *associated with the spatial instantiation rather than with the original informational representation*.

So, quite unexpectedly, the proposed framework might vindicate the *evolutionary* version of the Plato’s view of reality as the instantiation of (informational) Forms, since in the above scenario—using the language of the Plato’s ‘shadows-in-the-cave’ metaphor—the observed spatial events, which have been so far considered as primary, are, indeed, ‘shadows’ of the basic, informational, events lying *outside* the spatial realm.

One might be tempted to suggest that the new formalism replaced the mind-matter duality with another, spatial-temporal duality. *In some sense*, this might be true, but there is, especially from the scientific point of view, a crucial difference. Above all, the matter mind-matter duality splits the basic reality, as it is perceived by us, into the *two incommensurable realities, with the unknown (and unknowable) connection between them*. On the other hand, I would not use the term ‘duality’ to designate the latter, qualitatively different kind of relationship (if it turns out to be true), since here we are dealing with the universal *precedence* of temporal, or informational, representation over the spatial one, and hence, with a relatively clear connection between them.

Incidentally, already in 1920, the English philosopher Samuel Alexander made the following amazing observation: “Time is the mind of Space and Space [is] the body of Time.”[32]

On the formal side, as we will discuss in Chapter 7, the present formal concept of space, i.e. the vector space, does not allow one to model the concept of an expanding space, which seems to be necessary if we are to accept in some form the reality of the Big Bang theory. While the concept of process, encapsulated by the ETS struct evolving in time, seems to capture that reality quite naturally. In general, the conventional mathematical concept of a point in some (even abstract) space—in contrast to the concept of struct—does not allow us to deal with the structurally evolving side of reality: the spatially motivated transition from one point to the other does not and *cannot* capture the ubiquitous formative (or some would say creative) side of reality, which is so clearly exhibited by the biological developmental processes.

As a result, despite investing enormous human and technological resources, the overwhelming difficulties we encountered in understanding the nature of quantum mechanics and in applying it to chemistry, biology, and neuroscience is an indication that the promissory notes that many physicists have given us might be just part of wishful thinking. Again, the widely misunderstood critical point here, which will be discussed throughout the book, is that *all basic mathematical models* physicists have relied on have intrinsic limitations restricting their domain of applicability to the nonevolutionary environments, i.e. to the environments that do not change *structurally*. But, as we have gradually learned, such environments capture reality during a relatively static stage of its development, and hence cannot address the *formative* structure of real objects or processes, which have been and will continue to evolve. So how can the scientists whose objects of study don't make any sense outside the larger, evolutionary, context assume the adequacy of present mathematical models?

I cannot help mentioning that, for example, most biologists have accepted the above promissory notes for their face value, concentrated on molecular biology, and in turn have issued their own promissory notes regarding the fast pace of progress of their own field, which have duped many biotechnology investors (for which, at times, they pay dearly[33]). Incidentally, the field that has issued, by far, the most of the unfulfilled promissory notes is Artificial Intelligence—concerned with the computer simulation and modeling of 'intelligent' processes—and the reasons for its lack of progress are similar to the above: the formal models that researchers have relied on are fundamentally inadequate.

Returning to our central question raised in Section 2 regarding the mind-matter gulf, it is not difficult to see now that the struct—as capable of carrying both kinds of information, *subjective* and *objective*—ensures the agreement of their *forms*, which leads to the removal of that gulf. In other words, the disappearance of the gulf is ensured by the fact that the *result* of the structural 'measurement' performed by an agent on an object takes the same *form* as the object's real representation in Nature. Indeed, given some object, the 'subjective' struct is constructed by an agent during its interaction with this object relying on *the agent's (evolutionary) supply of events*. This is the agent's representation of the object, which is still the object's formative history *as perceived by the agent* And the 'objective' struct is maintained by Nature and encapsulates the entire process of the object's formation, based on *the complete set of events*. Of course, the agent's supply of events, because of its evolutionary origin, is 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 many physicists and philosophers, who rely on the conventional scientific concept of time: there is no *qualitative*, or structural, difference between the subjective and objective 'times'.

Moreover, the unity of the objective and subjective *forms* of representation brings about the unique and also critical feature of the proposed structural formalism: *the unity of its syntax and semantics*. As we know, in any spoken language or a scientific model, the syntax is not related to the semantics: *our choice of symbols has no relation to the structure of the actual objects they signify*. For example, in any language, the syntactic structure of the word "tree" has nothing to do with the semantic, or actual, structure of a tree. And in science, we have the same situation: the syntax of the equation of the Earth's orbit has nothing to do with the semantics of this orbit (which, presumably, should be understood via its formative, or evolutionary, history). While in the structural formalism, the chosen symbols, i.e. the events, are intended to be the 'mirror' copy of their real-world counterparts. So, as was suggested above, the structural formalism promises to radically change the nature and the role of representation in science. This, again, brings us back to the appraisal of the transitional period we are facing now in science, discussed in Section 2.

In fact, if the two hypotheses at the beginning of the last section—regarding the primary nature of all processes as the informational streams of structured events, and regarding the classes as constituting the primary units in the informational organization of the Universe—will be corroborated, we are faced with the scientific change of incomparable magnitude. And I do mean something much more radical than a simple declaration of "the matter myth", as it became popular to do among physicists.[34]

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

> Now it is characteristic of thought in physics, as of thought in natural science generally, that it endeavors in principle to make do with 'space-like' concepts *alone*, and strives to express with their aid all relations having the form of laws. [35]

And, as I mentioned above, the origins of this, absolutely dominant, status of "space" in mathematics and science go back to the decisive role of ancient measurement practices.

As an example of the radical change, the very notions of particle or object as material entities continuously persisting in space would need to be completely abandoned and replaced by those of spatially instantiated streams of events. Also, there appears to be no need for the mystifying and very confusing wave-particle duality, since, as we will discuss in Chapter 17, a stream of events—where each event has one incoming and two or more outgoing links (but possibly only one of them is spatially instantiated)—*directly* exhibits both particle- and wave-like properties. Of course, such claims about the nature of "particles" should not be that difficult to verify experimentally.

It is interesting that, as was documented by John Stachel [36], *throughout his career*, Einstein has been seriously and increasingly preoccupied with the possibility that the conventional, 'continuous', apparatus might be completely inadequate. For example, here are Einstein's opinions from two of his 1954 letters:

> I consider it entirely possible that physics cannot be based upon the field concept, that is on continuous structures. Then *nothing* will remain of my whole castle in the air including the theory of gravitation, but also nothing of the rest of contemporary physics. (ref. 36, p.286)

> 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. (ref. 36, p. 286)

So in addition to discarding "the matter myth", the whole methodology of scientific enquiry would have to change, including the (spatial) mathematics and our measurement devices. In order to understand the latter, one just needs to compare the two structures depicted in Figures 1.4 and 1.5, *each guiding the development of the corresponding measurement devices*. The design of our present measurement devices is geared towards relying on a single event to register the homogeneous structures shown in Figure 1.4, i.e. the natural numbers, while the new measurement devices should rely on several *fixed* types of events to register the corresponding structs. As I already mentioned in Section 1, this is not to say that there would not be a transitional period, when the familiar measurement devices will be used.

We often hear the statement that "mathematics is the science of patterns" [37] and it helps us to do all kinds of pattern recognition. I like this metaphor, but now *we have to own up to it*: since the new, structural, mathematics was motivated by the needs of pattern recognition, we should be motivated to change our scientific 'spectacles' in order to see a much greater variety of patterns in Nature. For example, instead of the old form of pattern prediction via equations, we will be able to rely on a much more general form of pattern prediction, the class representation, to predict the structure of future processes belonging to a particular class of processes.

Moving on to the implications outside science, in Section 2, I quoted sympathetically four quite different sources commenting 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: in the first paragraph of Section 2, I pointed out that, from the very beginning, the fathers of the Scientific Revolution have deliberately removed our minds or any kind of mind from the scientific picture. So the reason the Universe appears to be indifferent to us—or, as Steven Weinberg famously puts it, "pointless" [38]—is that *we* made it to look so.

Thus, 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 simplistic metaphors of present biology ("selection"), and computer science ("computation") have long outlived their usefulness, and could not have done it for us. And so, even here, the newly resurrected, in an informational setting, the old metaphor of classes and induction—motivated by bringing the Nature's 'mind' into the core of our scientific picture—appears to be exactly the right, *non-trivial*, metaphor that can literally reanimate and reinvigorate our vision of the Universe. The reality of classes in Nature may turn out to be just the right, informational, embodiment of our deeply seated, perhaps for a reason, prehistoric animism.

However, after being conditioned by a long scientific period of simplistic metaphors, we should have enough wisdom, including *patience,* to allow ourselves to reap the full benefits of the new metaphor. We should also come to our scientific senses and evaluate very carefully the promissory notes we have been given during the last fifty years by the hard core 'materialists'. A common scientific sense should tell us that our model of reality must be able, at least to some extent, to account for and clarify *immediately* the structurally evolving—some would say creative—nature of that reality, which the conventional numeric models, in view of their intrinsic limitations, simply cannot do. In other words, the candidate new formalism should account for those basic (evolving) features of reality *directly, as part of its intrinsic structure*: no magic should be expected in the future.

As far as the scientific investment in the proposed undertaking is concerned, we should keep in mind that the risks are not as high as they may seem, especially compared with the benefits, which would include, for example, abandoning our perennial complaint that "the real essence of substances is forever unknowable". First, many physicists have already agreed "that events and not particles constitute the true objective reality" [39]. On the formal side, it means that we should be replacing the spatial, point-based, or numeric, representation of reality by its *intrinsic* or *structural* (event-based and temporal) representation: again, we do know that there are no 'points' in Nature, just events. And second, besides the fact that *all biological organisms*, including us, are relying on induction and classification each hour of every waking day, there are also *many* thousands of people around the world working in various data processing fields relying on this metaphor in their day-to-day work, and their number is increasing quite rapidly.

Accordingly, to set the stage, it is appropriate to begin the book proper with the next chapter, providing a brief outline of the history of induction—the process that might be the key to the unraveling of the informational organization of Nature. Finally, when evaluating this history as it relates to the last century, one general point should be kept in mind: the tragedy of our present scientific predicament—which also applies to many social/political problems we are facing today—is partly related to the fact that the increasingly fast pace of our busy lives has not been conducive to the *necessary* radical rethinking of our basic scientific postulates.

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. It was the Cornell physicist N. David Mermin who coined that phrase to designate a certain dominant interpretation of (attitude in?) quantum mechanics, although now it is often attributed to Dirac or to Feynman http://physicstoday.org/journals/doc/PHTOAD-ft/vol_57/iss_5/10_1.shtml?bypassSSO=1 [accessed 30/06/2011].

4. Milič Čapek, *The Philosophical Impact of Contemporary Physics*, D. van Nostrand, Princeton, 1961, esp. the last section of Chapter XVI.

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

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

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

8. Ian Marshal 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.

9. Ivor Leclerc, *The Philosophy of Nature*, The Catholic University of America Press, Washington, D.C., 1986, p. 208.

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

11. 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 .

12. 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. Rep. TR07-187, Faculty of Computer Science, University of New Brunswick*, 2007, http://www.cs.unb.ca/~goldfarb/ETSbook/ETS6.pdf .

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 .

13. 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.

14. 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.

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

16. See Part III of the first paper in note 12.

17. 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."

18. 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 he introduced the concept of negative entropy, or negentropy.

19. See for example, John Barrow and Frank Tipler, *The Anthropic Cosmological Principle*, Oxford University Press, 1986 or Wikipedia contributors, Anthropic principle, *Wikipedia*, *The Free Encyclopedia* http://en.wikipedia.org/w/index.php?title=Anthropic_principle&oldid=436223231 [accessed 30/06/2011].

20. See my paper in Note 11.

21. 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.

22. John Bell, Against 'measurement', *Physics World*, August 1990, pp. 33–40. I am convinced that the inadequacy of the conventional concept of measurement is due to the inadequacy of the entire (spatially motivated) conventional numeric framework.

23. 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 .

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

25. 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. Ahlibininski.

26. 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 .

27. 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.

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

29. 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.

30. 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.

31. George Musser, How quantum entanglement transcends space and time, FQXi blog article, Oct. 25, 2011, http://fqxi.org/community/forum/topic/994 .

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

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

34. 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.

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

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

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

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

39. 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. 131–32 and Lee Smolin, *Three Roads to Quantum Gravity*, Basic Books, 2001, pp. 53, 210–11.

Useful terms

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

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

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

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

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

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 the object came into life, i.e. how it was generated or how an *agent* perceives it

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

class representation – the informational ‘recipe’ for constructing, or generating, the representations of all members of the class, i.e. of the corresponding structs; the ‘recipe’ 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"

Basic points

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

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

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

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

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

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

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

- The reason one can expect the struct to be adequate for the needs of induction has to do with the fact that the information captured by it is directly relevant to the recovery of the corresponding class: according to the definition of class adopted in ETS, *all objects from the same class have similar 'formative' histories* and each of those *is recorded explicitly in the corresponding struct*.

- The unique feature of the proposed formalism is two explicit postulates regarding the *informational structure of Nature*:

  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 is not meaningful—is an informational 'recipe', or algorithm, for constructing the representation of each class member.
- 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 events can be undone: the past does not disappear.
- The struct—as capable of carrying both kinds of information, *subjective* (when employed by an agent) and *objective* (when part of Nature)—ensures the agreement of their *forms* and leads to the removal of the mind-matter split.
- This unity of the objective and subjective forms of representation brings about the unique, among all languages or formalisms, feature of the proposed formal language: *the unity of its syntax and semantics*.
- 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 brief history of induction: What has been missing?

> Our only hope therefore lies in a true induction.
>
> Francis Bacon

> May we venture to hope that when Bacon's next centenary is celebrated the great work which he set going will be completed; and that Inductive Reasoning, which has long been the glory of Science, will have ceased to be the scandal of Philosophy?
>
> C. D. Broad (1926)

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

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

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

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

First, Aristotle is the founder of, and perhaps the greatest figure in logic, and hence the appropriate accolades by Popper: "Aristotelian logic is the theory of demonstrable knowledge; and Dante was right when he called Aristotle 'the master of all who knew'. He is the founder of the proof, the *apodeixis*: of the apodeictic [capable of demonstration] syllogism. He is a scientist in the scientistic sense and the theoretician of scientific proof and the authoritarian claims of Science." [1]

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

> [Aristotle] being a clever man, and a good logician, he finds that his assumption that there is demonstrable knowledge involves him in an infinite regress, because this knowledge, if demonstrated, must be logically deduced from something else, which in turn must also be demonstrated knowledge, and therefore in its turn deduced from something else, and so on.
>
> So he gets to the problem: how can this infinite regress be stopped? Or: what are the real original premises, and how do we make sure of their truth? He solves this fundamental problem of knowledge by the doctrine that the real original premises are statements of definitions. … Definitions, on the other hand, give to words the meaning by convention and are therefore certain (analytical, tautological). But if they are only conventional, and therefore certain, then all *epistêmê* is truth by convention and therefore certain. In other words, all *epistêmê* is tautological, deduced from our definitions. This conclusion Aristotle does not want, and he therefore proposes that there exists, on the other hand, also definitions that are not conventional … they are the result of "seeing the essence of a thing", and so synthetic; they are the result of induction [*epagôgê*].
>
> This seems to have been the way in which induction entered into the theory of scientific method, of epistemology. According to Aristotle, induction is the procedure of leading the pupil (or the scholar in the sense of the learner) to a [state] … , from which he can see the essence of the object of his interest. The description of this essence he then lays down by definition as one of his fundamental principles, the *archai*. …
>
> [Aristotle] does believe that we somehow arrive, by its [induction's] help and by the intuition of the essences of things … , at statements that describe these essences, or some essential properties, and that these statements are, as definitions, true and certain and can serve as the ultimate premises of *epistêmê*, of demonstrated scientific knowledge.

These fragments by Karl Popper are taken from Chapter 1, titled "Introduction: Aristotle's invention of induction and the eclipse of Presocratic cosmology", in one of his latest books.[2] In this short introduction, Popper several times accuses Aristotle of "double thinking" and "double talk", and that he "had a bad intellectual conscience when he introduced his theory." This is not the place to address these accusations but in Aristotle's defense, I must mention at least two points. Both *Analytics* were probably a record of his courses produced when he was relatively young (close to 347 BC) and, hence, did not come out of his pen: it was compiled and edited by the students and later lecturers at the Aristotle's Lyceum. That should (partly) take care of the "double talk". As to the "bad intellectual conscience", I think accusing Aristotle of it makes no sense in light of what we know of his character.

However, coming back to the "double thinking" and "double talk", it is only fair to Aristotle to note that even now, after *almost two and half millennia*, we have not moved an iota towards clarifying the ideas proposed by him. After all, 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, which were mentioned in Section 1.5 (see also Figure 1.6) of the last chapter and will also be discussed in Section 9 below but mainly addressed in Chapter 14. So the persistent denial of the existence of such nontrivial, but central, process as induction, including by Popper (see Section 5 below), is related, as I mentioned in the previous chapter, to the inability of both human languages and the numeric formalism to approach this process meaningfully and productively. One cannot blame Aristotle for not being able to fully realize and articulate the latter more than two millennia ago!

So what did Aristotle proposed? *In contrast to a vast majority of modern logicians*—who continue to ignore induction—being the founder of logic, he realized that propositional knowledge, i.e. knowledge expressed in propositions, is completely divorced from the physical world and hence needs some grounding in the actual objects and processes. Moreover, he also realized that "the method by which even sense-perception implants the universal is inductive"[3], and so we should rely on this "method" to ground our propositional knowledge. This proposal seems to me quite reasonable and, given its time, even profound.

It is interesting to note that, *before I was aware of the Aristotle's proposal*, in a paper written more than twenty years ago[4], I actually outlined a preliminary formal mechanism for realizing his proposal:

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

As was mentioned in the previous chapter, a much more improved version of that proposal, i.e. the ETS formalism, will be outlined later in this book.

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

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

So, although all ancient civilizations, including Greeks, spontaneously viewed nature as an organism, what should be of particular interest to us is that Aristotle was trying to develop a general theory of matter as an 'organism'. As we will discuss in Chapters 5 and 6, with the Scientific Revolution, this undertaking was reversed.

One more issue is worth mentioning in passing: the perception of Aristotle by the participants of the Scientific Revolution as a 'poor' scientist, which still lingers today, can be partly attributed to the prevalent at that time scholastic, or dogmatic, form 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 in the last year of his life: "Linnaeus and Cuvier have been my two gods, though in very different ways, but they were mere schoolboys to old Aristotle." [7]

2. Francis Bacon and the one-sided acceptance of his inductive methodology

We have no historical evidence of any major developments of induction until Francis Bacon (1561–1626), who is considered to be one of the fathers of the "scientific method". In many ways, Bacon is a very exceptional star that shines brightly even among the brightest stars of "the century of geniuses", as the 17th century has been aptly called. His literary skills and insights into human nature suggested to some experts that he was the one who publish his literary works under the pseudonym of Shakespeare.[8] But for us, Bacon is particularly important since he was *the only one* among the founders of the "scientific method" who inverted the traditional priority of deduction over induction and *insisted that induction is the foundation for the development of all sciences*.

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

Bacon was not a typical philosopher: he did not believe that "the concepts embedded in common speech would prove to be the ones needed in a reformed natural philosophy—indeed quite the contrary." [9] Thus, in contrast to almost all—even the last century's—philosophers and logicians, he already realized that induction cannot be properly addressed relying on the common language. Bacon also realized that

> in order to furnish this induction or demonstration well and duly for its work, very many things are to be provided which no mortal has yet thought of; insomuch that greater labor will have to be spent in it than has hitherto been spent on the syllogism. [10]

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

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

> he never supposed that his method could be described in detail, prior to its employment in actual investigations. The specimen given in the *Novum Organum* … was explicitly described as a First Vintage,

> or provisional interpretation (*interpretatio inchoata*, II. 20); a full account would have to wait until the final part of the *Instauratio Magna*, the *Scientia Activa*, which was never written, or indeed even begun. [11]

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

I should point out another Bacon's foresight, which he actually repeated twice in *Novum Organum* and which has appeared to many quite puzzling. Without naming induction explicitly, he mentioned that, with the development of induction, the previous need for the extraordinary insights during scientific discoveries is reduced: "the course I propose for the discovery of sciences is such as leaves but little to the acuteness and strength of wits [intellect], but places all wits and understandings nearly on a level." [14] And indeed, in contrast to the numeric representation, under the proposed structural representation, most patterns in nature can now be discovered much easier *than before*, simply because they are *explicitly* present in the representation itself and just need to be 'extracted' (see the example in Section 9 below).

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

The *experimental* orientation of his works made Bacon, and in particular the *Solomon's House* in his *New Atlantis*, perhaps the central influence in the establishment of the Royal Society and earned him the title of "Father of Experimental Philosophy". Both Newton and Darwin, among other scientists, professed that in their work they followed "true Baconian method". Interest to Bacon in the second half of the 17th century Europe was enormous: in the Netherlands, there were forty-five, in Italy, fourteen, and in France, thirty three printings/editions of his works before 1700. "The Académie Royale des Sciences, founded in 1666, was created by Colbert, chief minister to Louis XIV, in what Colbert referred to as 'the manner suggested by Verulam' [in 1618 Bacon was made the Lord Verulam]." [12] Over a century and a half after Bacon's death, Kant's magnum opus, *The Critique of Pure Reason*, was dedicated to him. However, in the English speaking world, epistemologically most obscure last century, true to itself, did not accepted the Bacon authority, mainly because of his heavy inductive leanings. So we are left with the one-sided acceptance of his legacy.

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

As Plato and Aristotle before him, Bacon also had to deal with Forms, and, as was the case with his illustrious predecessors, his concept of Form could not have been sufficiently clear, although his inductive algorithms were much more sophisticated. In the opinion of some researchers, Bacon emphasized Form's "material translation in terms of 'configuration', 'structure', or 'texture' of bodies" [13] 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.

One should realize that 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 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 is clear to me that, once a satisfactory choice of the representational formalism is made, the concept of class in it should not present any substantial difficulties.

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

3. Hume's "Problem of Induction"

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

Hume proposes that we are simply relying on the premise that the future experience will resemble the past experience. Such principle was later called the "uniformity of nature" (and if one wants to be generous, it could be seen as a very rudimentary version of the second postulate in Section 1.5). Hume's suggestion regarding the issue of the rationality of induction is basically this: our reliance on, or belief in, induction is not completely rational since we cannot supply any convincing arguments for it, but in a pragmatic sense this belief is 'rational', because it would be irrational not to employ something that has performed so exceptionally well.

> Most fortunately it happens, that since reason is incapable of dispelling these clouds, nature herself suffices to that purpose, and cures me of this philosophical melancholy and delirium, either by relaxing this bent of mind, or by some avocation, and lively impression of my senses, which obliterate all these chimeras. I dine, I play a game of backgammon, I converse, and am merry with my friends; and when after three or four hours' amusement, I would return to these speculations, they appear so cold, and strained, and ridiculous, that I cannot find in my heart to enter into them any farther. [15]

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"[16]. However, besides spawning the new area of epistemology ("justification of induction"[17]), amazingly, what some philosophers have concluded from Hume's discussions, in contrast to him, is that, since we do not have any *rational justification* of induction, there may be no such thing as induction. Not surprisingly, the most prominent and radical doubter, Popper, appeared in the last century, and we will return to him in Section 2.5. The following humorous depiction by Bertrand Russell of Hume's "problem of induction" testifies to its notorious status in the last century.

> There is a peculiarly painful chamber inhabited solely by philosophers who have refuted Hume. These philosophers, though in Hell, have not learned wisdom. They continue to be governed by their animal propensity towards induction. But every time that they have made an induction, the next instance falsifies it. This, however, happens only during the first hundred years of their damnation. After that, they learn to expect that an induction will be falsified, and therefore it is not falsified until another century of logical torment has altered their expectation. Throughout all eternity surprise continues, but each time at a higher logical level. [18]

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."[19]

Nevertheless, if corroborated, the second postulate at the beginning of Section 1.5 *plus* the appropriate inductive learning procedure within the proposed structural formalism give a *complete* rational justification of induction. Indeed, if Nature is informationally organized by means of classes and the mechanism by which we learn them is universal, there is absolutely nothing surprising about our inductive capabilities. At the same time, two obvious points should be kept in mind. First, as I mentioned in Section 1.3, if a given set of examples (e.g. white swans) all belong to a *subclass* of some larger target class (all swans), one should not be surprised that only this subclass, rather than the larger target class, will be learned inductively. And second, the life of a class is intimately related to the lives of their members: they emerge, change, and fade away along with their members, so when relying on a particular class, we should always remember that it may change or expire, for the consequences of which we should not blame induction. Induction does not claim that the classes involved are fixed. In fact, as everything else in this Universe, a class is also a dynamic entity, at least at two levels: each of its members is changing with time and the overall membership is also changing (some members expire and some new emerge). I believe these considerations, taken together, should completely dispose of the ubiquitous Hume's "problem of induction", including its justification, considered the most difficult and unsolved epistemological problem.

4. Mathematics and induction: Poincaré against Hilbert and logicists

The French mathematician Henri Poincaré (1854–1912) was the greatest and most versatile theoretical and applied mathematician of his time and one of the top mathematicians in the entire history of mathematics. He was also an outstanding physicist of his time, a co-discoverer with Einstein of the special theory of relativity and contributor to *many* other fields in physics, including electromagnetism and optics. “Poincaré was described—by Popper—as the greatest philosopher of science ever.” [20]

At the end of his life, Poincaré was engaged in an important debate with the *logicists*—the growing group of mathematicians and logicians, including, at that time, Peano, Russell, and Zermelo—whose aim was to found mathematics *entirely* on logic, i.e. on very simple and very transparent (symbolic) principles. After Poincaré’s death, another great mathematician David Hilbert spearheaded logicism, which, however, lost steam when Kurt Gödel’s proved his famous result on the incompleteness of arithmetic in 1931. But here, we are interested in Poincaré’s important observations—in the debate with logicists—on the role of induction in mathematics, which logicists attempted to eliminate from mathematics as not a ‘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.

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

> Syllogistic [i.e. logical] reasoning remains incapable of adding anything to the data that are given it; the data are reduced to axioms, and that is all we should find in the conclusions.
> [Then he talks about the process of “verification” in mathematics which involves direct substitution of concrete numbers into a formula to verify it.] *Verification* differs from proof … because it leads to nothing. It leads to nothing because the conclusion is nothing but the premises translated into another language. A real proof, on the other hand, is fruitful, because the conclusion is in a sense more general than the premises. … There is no science but the science of the general. It may even be said that the object of the exact sciences is to dispense with these direct verifications.[21]
>
> 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 briefly discussed in Section 1.5.] The analytical process 'by construction' does not compel us to descend, but it leaves us at the same level. We can only ascend by mathematical induction, for from it alone can we learn something new. *Without the aid of this induction,* which in certain respects differs from, but is as fruitful as, physical induction, *construction would be powerless to create science*.
>
> … this induction is only possible *if the same operation can be repeated indefinitely*. That is why the theory of chess can never become a science, for the different moves of the same piece are limited and do not resemble each other. [My italics] [22]

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] [23]

As we can see, Poincaré—who also gave us still unsurpassed introspective account of the role of the subconscious in (mathematical) discovery[24]—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 [25], rather than its strength, as I have been suggesting: if Nature is indeed organized via classes, induction is the most 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? Partly, because the last century—which, in many ways, was sleepwalking towards a radical transition later in the present century—on the one hand, has seen an increasing number of philosophical, and I would say irrational, attacks on induction, and on the other hand, its second half has, for the first time in history, witnessed the emergence of technologically driven enormous demand on induction. In fact, the latter demand has intensified to such an extent that, in addition to the original (engineering) field of pattern recognition dealing with induction, *many* 'new' fields dealing with *exactly the same problems* began to appear. The tragedy of it all, as Bacon also believed and as I discussed in the previous chapter, is that our future might be on hold because of this scientific immaturity. As the English philosopher C. D. Broad observed early in the century (in the second epigraph at the beginning of the chapter), induction has become the glory of science and the scandal of philosophy. Regrettably, the "glory" part is really an overstatement, though, interestingly enough, some philosophers argue that even the subconscious esthetic criteria scientists associate with a particular scientific theory are of inductive nature [26].

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

Karl Popper (1902–1994), originally Austrian, was later "widely regarded as England's greatest philosopher of science since Bertrand Russell" [27]. He developed a strong anti-inductivist stand starting from his first book *The Logic of Scientific Discovery*, originally 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. [28] Also, Popper's popular appeal is not surprising, if we keep in mind, first, that most of his work appeared in the second half of the last century and second, that his philosophy of science, as suggested by an admiring disciple, is about "rationality without foundations". [29]

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. So do not look here for any explanation of how our creative 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. But 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: 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." [30] But the question of induction is a completely different story. If we do throw away induction, as was suggested by Popper, then we are in deep trouble, since, in addition to what was said above, it is induction alone that allows us to extrapolate the past performance of a theory into the future. Of course, if the ETS formalism is corroborated, the question of the utility of induction becomes completely superfluous.

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

Thus, if anything, this 'paradox' is a clear example of why present logical languages are not suited for dealing with induction, which was, probably, already realized by Aristotle when he proposed to base logic on classes and induction (see Section 2.1). But modern philosophers are indefatigable: Hempel's paradox "illustrate a problem where inductive logic violates intuition. It reveals the fundamental problem of induction". [31] In fact, quite sophisticated proposals for addressing the non-existing paradox have continued unabated up to the present time, including the paper under the intriguing name *The Doomsday Argument and Hempel's Problem*. [32]

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

> In 1954 Goodman [American philosopher] published a small book entitled *Fact, Fiction and Forecast*. The word "grue" appears in Chapter III, Section 4, which is entitled "The New Riddle of Induction". Goodman asks us to consider emeralds [which are bright green precious stones] that have been examined before time *t*, and to suppose that all of them have been green. Thus, by time *t*, these observations [inductively] support the hypothesis that all emeralds are green and the prediction that if we happen to examine the next emerald after time *t*, it will be green as well. … Goodman introduces a new predicate ["grue"]. Something is grue … if it is examined before time *t* and determined to be green, or it is not examined before time *t* and it is blue. [33]

So the "paradox" has to do with the following situation: before time *t* all emeralds are both green and grue, but after time *t* they are, obviously green only. Hence, blame it on induction. In fact, "the new riddle of induction has become a well-known topic in contemporary analytic philosophy—so well known that only a philosophical hermit wouldn't recognize the word "grue". [34] Again, there is no 'paradox' here. We are dealing here with a member of a completely useless collection of all *possible logical descriptions* of the class of emeralds. But the natural question is this: Should we even attempt such descriptions until we come to grips with the concept of class, including its precise definition, i.e. the concept of *class representation* (outlined in Section 1.5)? If anything, this 'paradox' strongly suggests that we should not, since we would be wasting our time. And when we do have a satisfactory definition of the class, we will see that we need to develop new kinds of 'logical' languages that will allow us to 'read of' more adequately the 'content' of the class representation. That is all I wish to say about the "new riddle of induction".

Before leaving philosophers, I should also mention one unusual case of the anti-inductivist stand, that of the towering figure of linguistics, Noam Chomsky, whom I have already mentioned at the end of Section 1.5. The peculiarity of the situation is that, while Chomsky introduced a very important idea of generativity in cognitive science—with emphasis, as ETS does, on the importance of formative structure—the *particular form* of generativity, *Post production system* (which was borrowed from computer science), somehow led him to the wrong conclusion about the reality of induction. [35] Ironically, the same computational model, which led Chomsky to deny induction, has motivated the development of ETS formalism. [36] I will come back to Chomsky's argument in the last paragraph of this chapter.

As philosophers of the last century were unsure what to make of induction, engineers and other specialists were discovering its enormous *practical*, including military, utility. Thus, in the late 1950s, the mainly engineering field of *pattern recognition*, or patterns classification, emerged, with its numerous applications to: handwritten and printed character recognition, fingerprint classification, image and face recognition (including satellite image recognition, military target identification, missile terrain navigation), speech recognition, text and document classification, robot navigation, computer-aided medical diagnosis, mineral discovery, forestry (e.g. classifying infested areas based on their satellite images), agriculture, and many, many other applications. The *practically unlimited* range of applications should not come as a surprise at all, since induction—as I mentioned in the previous chapter and will further discuss in Chapter 10—is our *main* tool for making sense of the external world.

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

One should keep in mind that, amazingly, this is the best that computer science can offer *after fifty years of developing various search techniques*. Why has the progress in this direction been so negligent? The answer is quite obvious: as will be discussed in Chapter 11, computer science has never dealt with the *general* issue of semantics, which, I believe, can be properly addressed only in the above context of classes. After all, semantics *must* be of perceptual origin (there are no other reasonable alternatives), which implies that the meaning of a phrase or a sentence can only emerge as associated with a particular abstract class, with which many other, semantically equivalent, phrases are also associated. This idea, although in a somewhat more muddled form, has also been guiding the development of *cognitive linguistics* [37], a relatively new area of linguistics. We will come back to these issues in Chapter 18. Of course, I do expect that relying on the ETS formalism one would be able to specify any query much more accurately than relying on its imprecise (ordinary) language formulation.

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

Although this will draw the wrath of many researchers in these areas, I am convinced that, regrettably, 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—there is still a small group of researchers working under the name of "grammatical inference"—which was inspired by Chomsky's generative grammars mentioned at the end of Section 1.5. For example, the connectionists originally emphasized the *architectural* side of the brain—"parallel distributing processing"[38]—while machine learning researchers originally emphasized formal logic and the computational side [39]. As a result of all these activities, one field of pattern recognition has unnecessarily fragmented into many, providing employment to many more people coming from a great variety of backgrounds, including physicists. Now, looking back at the ferment, and taking into consideration the massive human and material resources that were brought in, we have still very little to show for it in terms of our *basic* understanding of induction, and of course, without such basic insight no major applied breakthroughs are possible. What are the reasons for this lack of basic progress?

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

In this connection, it is also instructive to recall how the present leaders of the field, Vladimir Vapnik and 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. However, such attempts are extremely rare. [40]

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

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

If the answer is yes, then the discovery of these principles must form the main research direction in pattern recognition. It would be the main direction, since it would be general and principally new.

If the answer is no, then the pattern recognition problem … can be considered to be one of the directions in applied statistics.

We still don't have an answer to the above question and that is why the choice of the problem formulation has been, so far, a question of faith. The majority of researchers, however, have adopted the second point of view, and the theory of pattern recognition is now understood … [to be a particular direction in applied statistics]. [41]

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

6. The unreasonable expectations of probability theory

In this section, I briefly address the general role of probability (and statistics) in induction. In short, in this case, as was just mentioned by Vapnik and Chervonenkis—and *as has often been the case in science when the appropriate model of the phenomenon is not known—probabilistic considerations have taken over*. In what follows, I consider the case of continuous probability, as it by far dominates the applications, and for our purpose, it really does not make much difference which of the two cases (discrete or continuous) is considered.

As I suggested in the previous chapter, the key to unlocking the secrets of induction is a fundamentally new, structural, and considerably richer form of data representation. In other words, the numeric forms of data representation simply *do not contain enough information about the actual objects to decide their class identity*. This implies, in particular, that *no* new analytical machinery developed for the numeric (data) spaces *can recover the missing information*, simply because, from the very beginning, *that information is inaccessible in those spaces*. But since the discussion of the limitations of conventional mathematical spaces is postponed to Chapter 7, here I approach this topic in a limited way.

The main reason probability has been brought into inductive considerations has to do with the above mentioned inability of the numeric formalism to address adequately the concept of class: the relevant object structure is not accessible under this representation. The theory of probability is recruited to

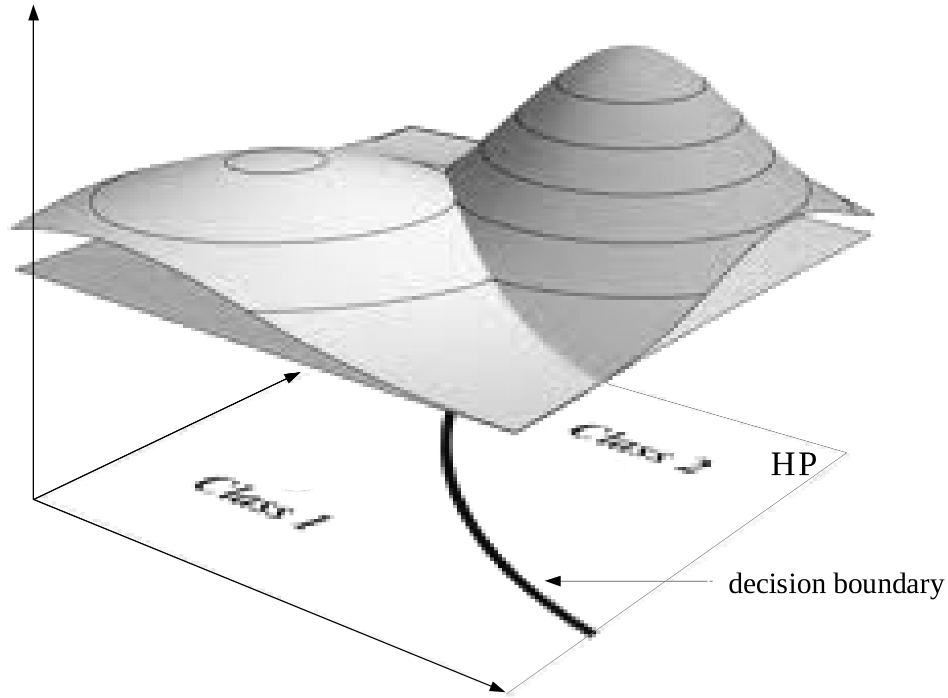


Figure 2.1: The input data is not shown, but each real object is represented by a point in the horizontal plane (HP), while the probability of the object is associated with the vertical axis. Two classes are considered, and each of the two shown probability functions (intersecting surfaces of different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

help delineate the approximate *decision* boundaries of the classes involved (see Fig. 2.1): if a new data point falls on the appropriate side of the decision boundary, this point is classified as belonging to the class assigned to that part of the vector space. It is instructive to note that if you are dealing with *a single class*, you, obviously, do not need any class boundary, but at the same time, you simply *cannot have a meaningful boundary*—in the same way when you had several classes—because you do not know where it should be, since there are no members of other classes to tell you were to stop. Hence, the case of a single class merely exposes the situation more clearly: *no decision boundaries can tell us what a class is*, simply because, again, the ‘glue’ that binds class members together has to do with their *formative* (non-numeric) structure. Indeed, if you think about it, it is plain silly to expect that some decision surface in the vector space can tell us much about the classes involved. But, *given the numeric form of representation*, *one simply has to live with all its inherent limitations*, and the decision boundaries are the only possible way to deal with the inductive problem (without having access to what a class is).

So the probability theory cannot help us understand *what* a class is, which would have been alright *if* the classes were actually figments of our imagination, as some still believe. This theory is not a magical tool that can *recover the information completely missing from the original data* *representation*. If anything, without the concept of class available to us, that theory, as has often been the case, has actually obscured the situation by covering up our ignorance. Regrettably, this role of probability theory has not been sufficiently recognized during the last century and not just regarding induction: partly the same situation occurred when we have been confronted with several deep phenomena, such as, for example, quantum and mind phenomena. Perhaps, in the case of induction, the inadequacies might be, to some extent, more transparent. Unfortunately, it is the fast pace of the last and present centuries that habitually forces us into the stop-gap probabilistic solutions. Of course, as a *provisional solution*, probabilistic treatment is acceptable, but what surprises me most is how entrenched such temporary solutions become in our super-busy age.

In light of the above, it should be clear why I decided not to deal here with numerous probabilistic treatments of induction developed in many of above applied fields concerned with induction, as well as with such topics as, for example, Carnap's inductive logic and confirmation theory, Reichenbach's frequentism, subjectivism and Bayesian induction, etc.[42] It might be of some interest, as well, 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'".[43] 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.[44]

Also of some interest is the observation made by the well known Russian mathematician Andrey Kolmogorov—who developed 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.[45]

7. Helmholtz's insight and the lack of progress with concepts 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. Because 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 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] [46]

Such were the conclusions of a great psychologist who was also a great natural scientist. Incidentally, although a good basic science education appears to be of crucial importance to a today's psychologist, in reality, it is quite rare, which, I believe, partly explains the lack of progress with concepts we are discussing next.

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

Four main theories of lexical, or 'word-sized', concepts have been proposed. But "in one way or another, all theories regarding the structure of concepts are developments of, or reactions to, the [original] *classical theory of concepts*".[47] *The classical theory* views concepts as composed of simpler, 'necessary and sufficient', concepts: to be a BACHELOR is to be MAN and UNMARRIED. *The prototype theory*—which originated in the 1970s in the work of Eleanor Rosch and co-workers—has a 'probabilistic' flavor and states that an object falls under a concept ***C*** if it possesses a sufficient number of features possessed by the members of ***C***: apple is a more typical FRUIT than plum, because apples share more features of fruits. The next theory of concepts—the *theory-theory of concepts*—"is the view that concepts stand in relation to one another in the same way as the terms of a scientific theory and that categorization is a process that strongly resembles scientific theorizing". The fourth theory of concepts is called *conceptual atomism*. "A radical alternative to all of the theories we've mentioned … is conceptual atomism, the view that lexical concepts have no semantic structure. According to conceptual atomism, the content of a concept isn't determined by its relation to other concepts but by its relation to the world." [48]

As has been the case in philosophy, in cognitive science, there are also the deniers of induction. The latest one is Edouard Machery, whose book *Doing Without Concepts* was just (July 2011) published.

So, the

Research into the nature of concepts is ongoing, in both philosophy and psychology, and there is no general consensus in either field as to the preferred theory of concepts. The theories above primarily address the tasks of answering questions about the analysis of concepts, along with the broadly epistemic questions about them … , while not always addressing the metaphysical questions directly. Yet the metaphysical issues do bear on the plausibility of one theory over another. As mentioned earlier, if concepts are abstract Platonistic entities, and not internal mental representations that are 'in the head,' then the classical view might escape some of the objections raised by prototype theorists. Alternatively, if concepts are 'in the head' as mental representations of some sort, and are structured in terms of the conditions one uses in sorting things as falling under that concept or not, then the classical theory looks bankrupt and the

> prototype theory looks superior to the rest. Whether the nature of a concept is to have such structure, as opposed to classical structure, a structure more along the lines of the theory-theory, some other structure entirely, or no structure at all, is a thoroughly unresolved matter. [49]

Recalling my above remark about the basic scientific education of psychologists, note *how far from the physical reality* all these theories of concepts are, and how immature they are. Also note a *very typical* for the overviews of the present theories of concepts and—they should be given credit for this—honest conclusion that everything is basically "a thoroughly unresolved matter". Thus, again, we see quite disappointing results of the extensive attempts to deal with classes outside the context of the appropriate representational formalism.

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

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

Moving on to *abduction*, it is the term introduced by Charles Peirce (1839–1914), probably 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 we were absent and then found the grass to be wet, we conclude that it had rained. Over the years, Peirce called the same process *retroduction*, *hypothesis*, and *presumption*.[50] 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*.

For us, the interesting question is this: Is abduction based on induction? It appears that, 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".[51] So 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 me, see for example the view of Francis Reilly [52] 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". [53]

Lastly, we deal with universals and particulars, a topic which dates back to at least Plato, but becomes increasingly prominent starting from 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. [54] Basically, a *particular* refers to a concrete object, while a *universal* refers to the characteristics—or properties, or features, or qualities, or attributes—that can be shared by particulars. In other words, we are dealing with concrete objects and their features. Philosophers who believe in the reality of universals are *realists*, while those denying it are *nominalists*. So nominalists believe that the 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 extreme positions. It seems that the whole issue was sparked by one of the most known Greek realists, Plato, who advocated this position with such great talent.

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

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

As I have hinted repeatedly, the main test for any inductive formalism is the quality of the concept of class it affords. As far I am aware, so far, the only formalism that offers any reasonable concept of class at all is ETS. For this formalism, a more complete answer to what a class is has to be postponed until Chapter 14, after the necessary auxiliary concepts have been outlined. However, in this section, to give an intuitive idea of the proposed concept of class, I illustrate it by presenting a very simple example. At this point, I encourage you to slow down the pace of reading. By way of preparation, review Figure 1.5 and note the general rule for attaching events in a struct: whenever a new event—with its incoming and outgoing links—is being 'attached' to a struct, *each of its incoming links must be* attached to *the same kind* of an outgoing link from a previous event, but there is no restriction that all such outgoing links have to come from the same previous event.

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 events shown in Table 2.1. (All straight line segments can be replaced by the curved ones, without affecting anything.)

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

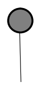
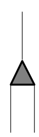
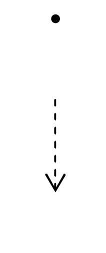
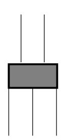
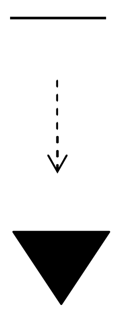
Basic events	A spatial interpretation of the events	
		the unique *initial* event: creation of a point; since this event initiates the generative process, it has no incoming links
 **P1**		the expansion of a point into a segment**;** the right outgoing link in event P1 corresponds the newly created point and the left one, to the old
 **P2**		the expansion of a segment into the triangle *by fixing one end of the segment and pivoting the other*; the middle outgoing link in this event corresponds to the newly created point, while the left and the right outgoing links correspond to the left and right ends of the original segment

Table 2.1: Observe the structure of the basic events involved. Since the top event is allowed to occur only once, at the very beginning, focus on the next two events. The incoming links of each event are associated with the points this event is acting on (input), while the outgoing links correspond to all the resulting points, *which include the old ones* (output). So when P1 or P2 is attached, the input point(s) ‘propagate’ through this newly attached primitive and are ‘open to business’ again.

Mindful of the needs of a popular exposition, for the chosen example—although I tried to preserve the spirit of the formalism—*everything* had to be simplified. And as more ‘realistic’ applications are more involved, this, *illustrative*, example is somewhat artificial. Also, *to simplify drawings, all event links shown are not differentiated*.

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

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

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

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

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

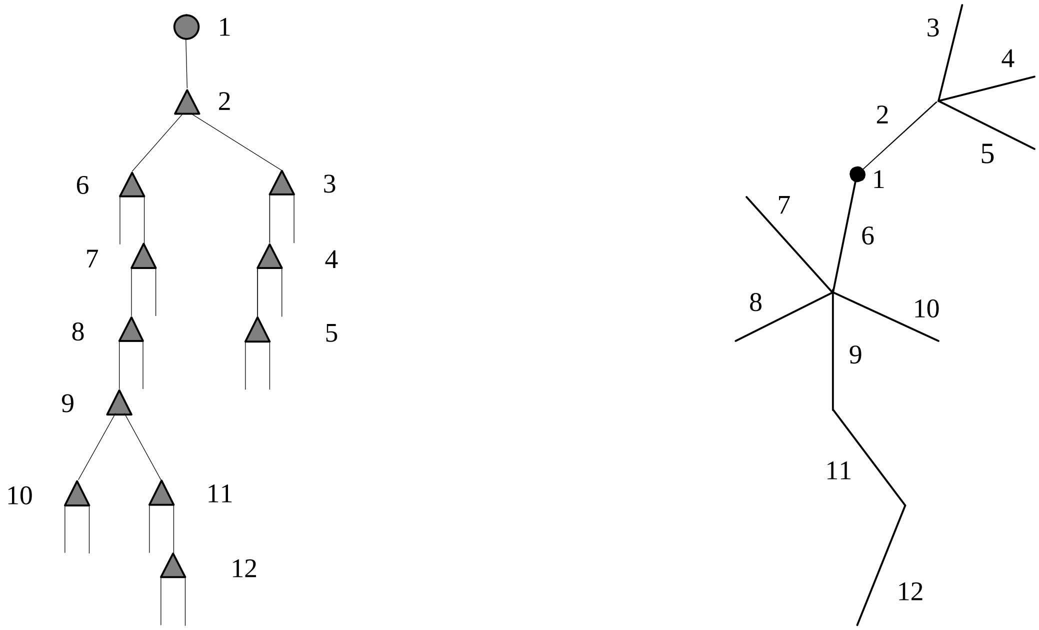


Figure 2.2: **Left**: Pictorial depiction of a struct from the class *Segments*. The adjective “pictorial” is supposed to sensitize you to the basic fact that, as in the case of numbers, pictures are not the actual abstract representations. The numbers indicate *the order in which the events occurred*. **Right:** the actual object corresponding to this struct.

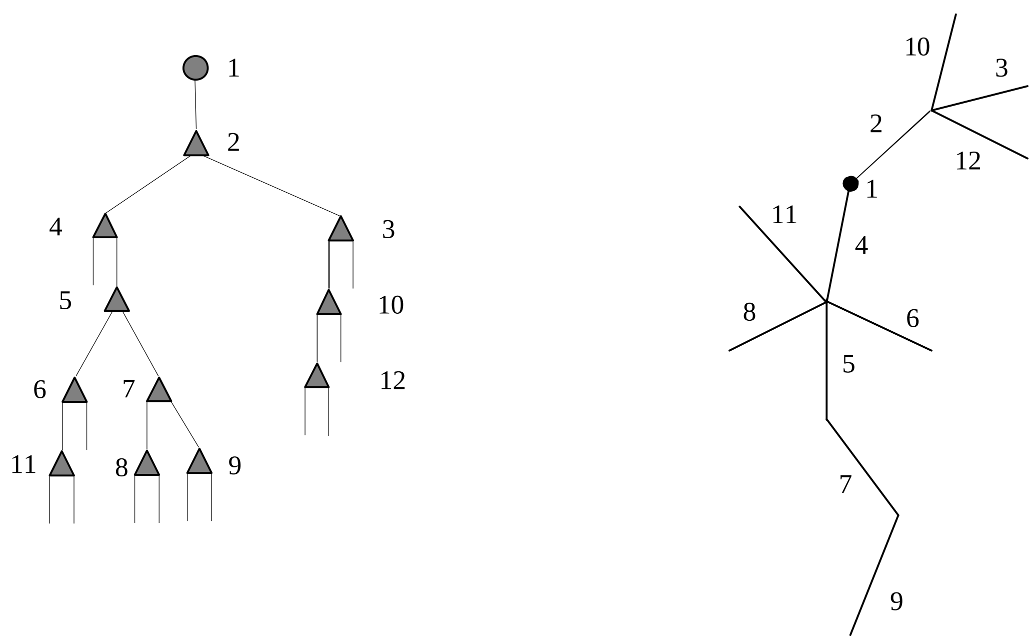


Figure 2.3: **Right**: The *same* object as in the last figure—which is, of course, also a member of the class *Segments*—but with the order of the events modified. **Left:** Pictorial depiction of the corresponding struct.

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

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

Let us return to our original question: How would the induction work for the above class *Segments*? Of course, induction relies on the "**training set**": a relatively small set of members of the class, "examples", on the basis of which the class representation has to be derived. Without going into the technical details, it is not difficult at all to see how—when given a sufficiently varied set of 10–20 examples, i.e. of the corresponding structs—the above mentioned class representation for *Segments* can be obtained. Basically, as the structs will have all possible combinations of event P1, the only restriction for each step in the class representation that will be learned from the training set is the 'obvious' one: use primitive P1 only.

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

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

I cannot help being inspired by the incredible possibility that when we are looking at structs like this we might be getting a glimpse of the beautiful and universal code of Nature, the *truly primordial*

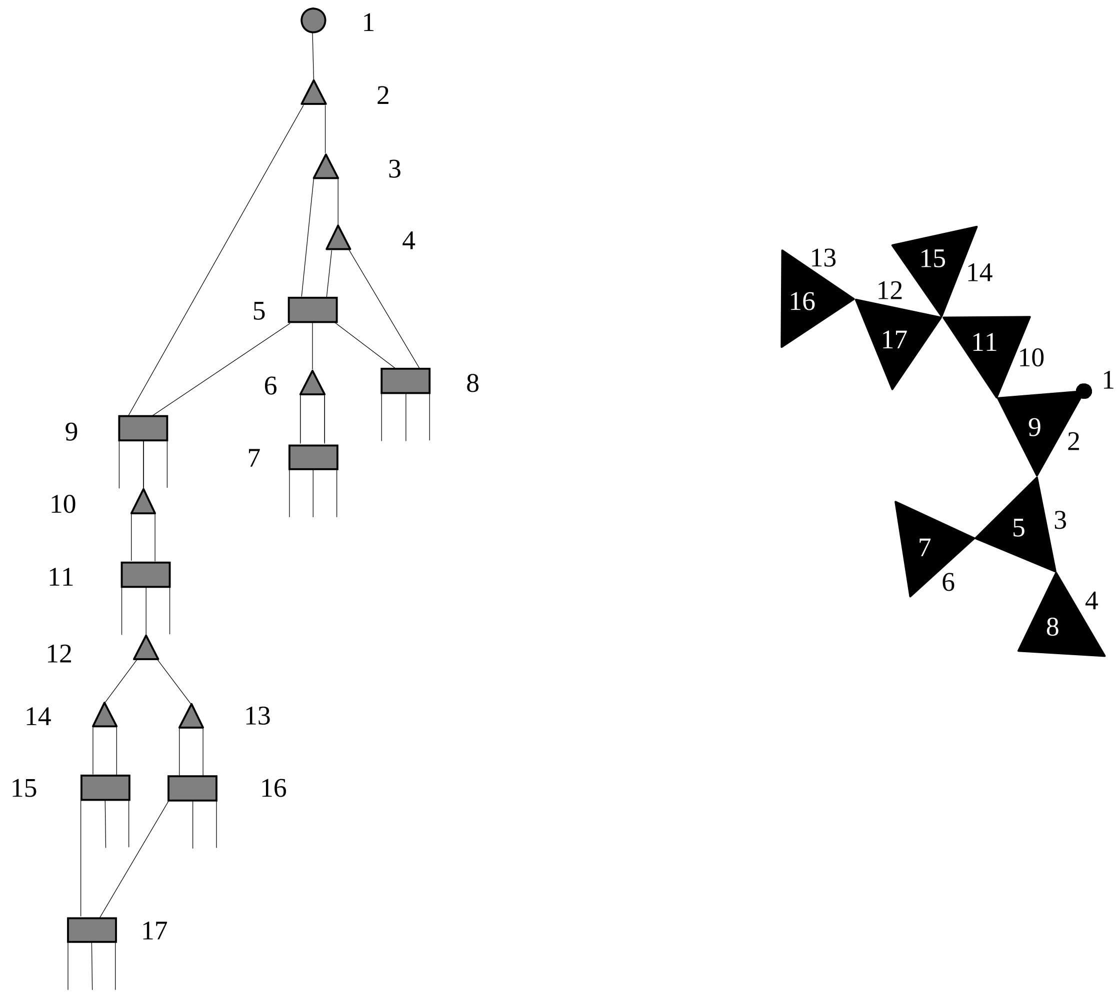


Figure 2.4: **Left**: Pictorial depiction of a struct from the class *Triangles*. **Right:** the actual object corresponding to this struct. The temporal order in the construction of that object is indicated, where a number near a triangle's side indicates the number of the segment which was later expanded into that triangle.

language in which the 'source code' for *each and every* process is written. And when we see an object, what we see is an evolving instantiation in space of the corresponding process.

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

In Chapter 14, we will come back to the PST world and consider *multilevel* classes in it, when the higher level class elements are composed of the lover level ones.

Note that the PST world as a whole exhibits the following general, and somewhat 'unnatural', feature: any fixed existing point in the geometric pattern can be expanded into a segment an unlimited

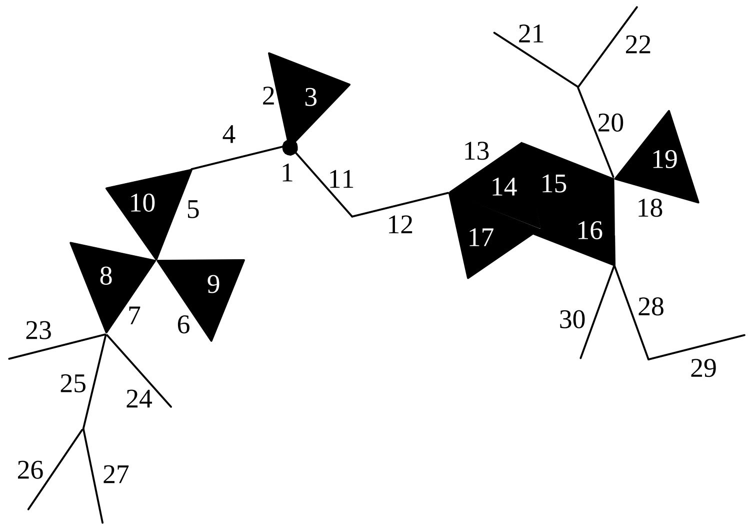


Figure 2.5: An example of a more general object from the PST world. The temporal order of the object generation is indicated, where a number near a triangle's side indicates that this side was later expanded into that triangle. Note that some triangles (15, 16, 17) were not generated in the way just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

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.

Before leaving this example, several important general observations and/or questions—to which we will come back in the last several chapters—are in order. The first one concerns the interpretation and the role of the structured events themselves. Recall what one of the leading mathematicians of the last century, David Hilbert, said about the axioms of geometry: that they are not about points, lines, and planes but about *any objects satisfying them*. As he put it "it must be possible to replace 'point, line, and plane' with 'table, chair, and beer mug' without … changing the validity of the theorems of geometry" [55]. The same applies to events: they are more universal, in the sense that their structure (not their spatial semantics) makes them applicable to many environments. For example, a more universal meaning of event P1 is that a single undifferentiated entity gives rise to two, possibly different undifferentiated entities, and such events abound in nature and applications, e.g. think of the first cleavage of the embryo during its development, when one cell subdivides into two. Such considerations suggest that the number of basic, *or elementary*, events in Nature might be quite small, in fact, much smaller than the number of known elementary particles.

The second general point was mentioned earlier, in the middle of Section 1.6, and is somewhat related to the first one: it is about the precedence of the structural representation over the spatial representation. In particular, since the events and the structs appear to be purely informational (with no spatial connotation) and have quite independent status: *Is it not possible, first, that the existence of structs must precede the spatial existence of the corresponding objects, and second, that the class representations are stored (and dynamically modified) in Nature?* One of the arguments in favor of this hypothesis is that all known patterns reoccur regularly and this would not be possible without some 'supervision' of all processes involved. If indeed this is the case, the spatial instantiation of objects, as was explained in Section 1.6, does not represent a difficult task, as the corresponding structs contain enough information to perform it.

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

On the basis of the first two chapters, you can safely assume that the topic of this section will be revisited again. However, in this brief section, we want to draw some relevant conclusions from what was discussed in this chapter.

We saw in the first section how, during the development of logic, its founder Aristotle was led to the conclusion that induction is a powerful principle *necessary* as a foundation on top of which his logic can be built (see also the third epigraph at the beginning of the chapter). Then, in Section 2, we saw how Hume, after a careful analysis of induction—relying, of course, on its verbal understanding—observed the *apparently* insurmountable obstacles in trying to understand it, which later on, during the last century, were turned into a tragicomedy (Section 5). Thus, all philosophical difficulties in dealing with induction stemmed from the naïve *misclassification* of this problem as logical or philosophical, rather than a new kind of *scientific* problem. In particular, first, there was no realization that induction is about the *classes* of (mainly) real, as opposed to fictitious, objects. And second, that the concept of class is a non-trivial concept that cannot be approached with 'bare hands': it is above all a scientific issue, where we are dealing with the fundamentally new, information processing, science. In particular, the main and unrecognized difficulty appears to be related to the need for a new kind of scientific formalism, within which the concept of class becomes transparent. But what kind of representational formalism (recall Section 1.1) do we need?

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

Incidentally, despite the false appearances, so far in science, we have only two examples of representational formalisms: the numeric formalism and its structural generalization, ETS formalism. Actually, as discussed throughout the book, strictly speaking, one should not call the numeric formalism a *representational* formalism, if it were not for the tradition sanctioned by the Scientific Revolution. As will be discussed in the next chapter, numbers emerged exactly for accounting purposes and are not suitable for an adequate representation of objects, which—as I argue throughout the book—should be about the objects' formative histories. Of course, it would be absurd to 'blame' for that the fathers of the Scientific Revolution: how could they have known about the concept of structural representation or that of formative structure?

Thus, it should be clear that, first of all, any human or logical language is not suited for the purpose of capturing formative object histories, hence all these ill-considered paradoxes discussed in Section 5. And second, the conventional, numeric, forms of data representation also cannot help us, since the only kind of formative history a point in space embodies is this: for example, a two-dimensional point (3, 4) was generated by 'walking' three steps along the first axis and then four steps parallel to the second axis. So if these two numbers represent the weight and the height of an object, how much of its formative history this point has captured? Indeed, how can this *point in space* convey the formative information about the object *it has never had*? Numbers were not 'designed' for the purpose of capturing non-trivial formative histories, end of story. It is *our* fault that, because of a lack of imagination, we blindly persist using the numeric representation 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.

Finally, I want to briefly address the "poverty of the stimulus" argument [56] introduced by Noam Chomsky in linguistics to support simultaneously two basic claims. The argument is that the grammar—that any of us is relying on when we exercise our mature language skills—is too complex to allow a child to learn it during the brief exposure to a relatively small number of sentences. On the basis of this argument, Chomsky, first, proposes that induction is irrelevant, and second, he proposes the "innateness hypothesis": there exists the "universal grammar" which is (genetically) innate to all of us. The second claim became quite controversial, since if accepted would lead to a host of similar hypotheses concerning other numerous areas of our expertise (mathematics, music, etc.). It is not difficult to see how Chomsky came to make such claim. Indeed, *given the conventional forms of representation*, the sentences a child hears are insufficient to deduce the underlying non-trivial *generative* patterns that Chomsky associates with our grammatical competence (see the end of Section 1.5). However, as the above simple example illustrates (Figs. 2.2–2.4), under the ETS representation, all previously hidden formative, or generative, information *becomes explicit* and hence the underlying generative pattern can now easily be learned based on a small set of examples, thus removing the need for the universal grammar.

Notes

1. Karl Popper, *The World of Parmenides: Essays on the Presocratic Enlightenment*, Routle4dge, New York, 2002, p. 276.

2. Karl Popper, *The World of Parmenides: Essays on the Presocratic Enlightenment*, Routle4dge, New York, 2002, pp. 2–3.

3. Aristotle, *Posterior Analytics*, eBooks @ Adelaide, 2006, Book II, Section 19, http://ebooks.adelaide.edu.au/a/aristotle/a8poa/book2.html [accessed 9/07/2011].

4. Lev Goldfarb, On the foundations of intelligent systems I: An evolving model for pattern learning, *Pattern Recognition*, Vol. 23, No. 6, pp. 595–616 (incidentally, the paper won one of the "Annual Pattern Recognition Society Awards for the outstanding contribution to the journal").

5. Capital 'F' is to distinguish *Form* as *eidos* (objective essence) from *form* as an appearance (*morphē*).

6. R. G. Collingwood, *The Idea of Nature*, Oxford University Press, 1945, p. 92.

7. Fr. Darwin (ed.), *The Life and Letters of Ch. Darwin*, 2nd edition, London, 1887, Vol. III, p. 252.

8. Wikipedia contributors, Shakespeare authorship question, *Wikipedia, The Free Encyclopedia*, http://en.wikipedia.org/wiki/Shakespeare_authorship_question#Sir_Francis_Bacon [accessed 14/07/2011].

9. J. R. Milton, Induction before Hume, *Handbook of the History of Logic*, Vol. 10, 2011, p. 12.

10. Francis Bacon, *The New Organon*, Book One, CV, eBooks @ Adelaide, 2006, http://ebooks.adelaide.edu.au/b/bacon/francis/organon/chapter1.html [accessed 9/07/2011].

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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

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 – a formal and reasonably general mathematical model of the space as we come to know it

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

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

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

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

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

BASIC POINTS

- Aristotle, *in contrast to practically all modern logicians*—who continue to ignore induction—being the founder of logic, realized that propositional knowledge, i.e. knowledge expressed in propositions, is completely divorced from the physical world and hence needs some grounding. Moreover, he proposed that in attempting this, we should follow the way "sense-perception implants the universal", and this is why he introduced the process of induction.
- Matter, according to Aristotle, is unrealized potentiality, and it is always and everywhere in process of organizing itself, i.e. acquiring various Forms. But matter completely disappears only when Form is fully realized and potentiality is resolved into actuality. Hence, Aristotle suggests, *pure actuality (information) contains no matter, and anything situated somewhere in space is 'material' (and not informational), because it might be somewhere else and still remain itself*.
- Aristotle was trying to develop a general theory of the organism that would be extendable to the entire Cosmos, but the Scientific Revolution reversed this undertaking.
- Francis Bacon is particularly important since he was *the only one* among the founders of the "scientific method" who inverted the traditional priority of deduction over induction and *insisted that induction is the foundation for the development of all sciences*.

- Bacon also realized that a “greater labor will have to be spent in it [induction] than has hitherto been spent on the syllogism [logic].”
- Bacon foresaw that relying on induction as a general ‘tool’ will allow scientists to make great discoveries in a more routine manner.
- Although a number great scientists, including, Newton and Darwin, professed that in their work they followed true Baconian method, one should admit that so far we are left with the one-sided acceptance of his legacy, which completely ignores his advocacy of the *developed* induction as a powerful tool for the advancement of science.
- The first prominent attempt to deal with the issues related to *the justification of induction* was that of David Hume. But the results, not surprisingly, were disappointing: induction is ubiquitous but why it should be true is not clear at all, except for one principle that he proposed which was later called the “uniformity of nature”.
- Unfortunately, in the 20th century, Hume’s unsuccessful attempt to find a ‘rational’ justification of induction was often seen as a proof of its non-existence.
- During the first decade of the 20th century, the greatest at that time mathematician Henri Poincaré was engaged in a debate with the *logicists*—the group of mathematicians and logicians, including Peano, Russell, Zermelo, and Hilbert—whose aim was to found mathematics *entirely* on logic, i.e. on very simple and very transparent (symbolic) principles, which, of course, excluded induction. His conclusion was:

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

- The transitional 20th century has witnessed a tragicomedy of induction: the increasing number of philosophical attacks on induction, and at the same time, for the first time in history, the emergence of technologically driven enormous demand on induction.
- Induction, if properly developed, should *unrecognizably* transform all search engines as we know them today: in response to your query, you should get a much more selective set of records that match you query *semantically*, i.e. based on its content, rather than relying just on some words or phrases in it, as it is done today.
- Excluding ETS, so far, despite the enormous investment of money and human resources, no *fundamentally new general scientific ideas* regarding the nature of induction were discovered or even proposed, with one, almost forgotten, exception of syntactic pattern recognition, which was inspired by Chomsky’s generative grammars.
- It is unreasonable to expect the probability theory to perform the miracle: *the information that is missing from the numeric object representation cannot be recovered by any analytical means*.
- One of the greatest scientists of the second half of the 19th century, Hermann von Helmholtz, concluded about induction:

> Inductive inferences, executed by the unconscious activity of memory, play a commanding part …
>
> It may be doubted that there is any indication whatsoever of any other source or origin for the ideas possessed by a mature individual.

- The extensive cognitive science research into concepts (i.e. classes) is at an impasse: the nature of concepts "is a thoroughly unresolved matter".
- With the development of induction, such concepts as abstraction, abduction, universals and particulars will wither away, since classes and induction will make them obsolete.
- The main test for any inductive formalism is the quality of the concept of class it affords. As far I am aware, the only formalism that offers *any reasonable concept of class* at all is ETS.
- In section 9, a simple example illustrates the idea of ETS representation and why it should play an important role in the construction of the class representation during inductive learning. In particular, Figures 2.3 and 2.4 illustrate the following critical point. Any 'visible' pattern *hides many of its possible formative histories, or its different generating processes*. And the latter are *lost permanently*, if the chosen object representation, e.g. numeric representation, is not capable of capturing this, as I claim, primary side of reality. In particular, the examples illustrate that under a non-structural representation we are missing *many classes of objects*, i.e. they become invisible.
- Thus, already in this chapter, we begin to see why the *generative side* of objects is so crucial and hence should be captured by the object representation, hence the need for a structural representation. The reason all historical attempts to deal with induction have failed has to do precisely with the inability of a spoken language or the numeric formalism to capture that—generative and primary—side of reality.

Chapter 3

The original sin: From counting to measuring

1. Five stages in the development of natural numbers

2. Registration of events and the temporal origin of natural numbers

3. Some of the first symbols: Notches, knots, and multi-shaped tokens

4. Before numbers: counting

5. The standard sets of trade goods

6. The development of trade and the concept of natural number

7. The gradual blurring between the ordinal and cardinal meanings of a natural number

8. What is a measurement?

9. The Greek miracle: 'Dissolution' of natural numbers in the reals and the transition to modern mathematics

Chapter 4

The forgotten scientific revolution

1. The emergence of science in the Hellenistic period

2. The development of mathematics

3. The development of sciences

4. The development of technology and medicine

5. Why has the Hellenistic revolution been 'lost'?

Chapter 5

The die has been cast: The fateful philosophical and scientific decisions in the 17^{th}–18^{th} centuries

1. The background: Quantification of Western society in 13^{th}– 16^{th} centuries

2. Matter as structureless substance not subject to becoming

3. The decisive role of space: Spatial extension as the essence of material substance

4. Mind is not a spatially extended substance

5. The motion as a simple change of place under the external 'mover'

6. The concept of force: The external mover

7. The homogeneity and immutability of the Euclidean space

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

9. The corpuscular-kinetic view of Nature

10. Mathematics as the divine tool for organizing the Universe

Chapter 6

The accompanying radical dualism

1. Matter as radically non-mental or non-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

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

2. The adventures of the concept of force

3. The concept of field

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

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

6. Quantum mechanics: Continuous formalism for a discrete phenomenon

Including: quantum indeterminacy relations as invalidating the physical applicability of the differential-integral framework

Including: indeterminacy as invalidating the concept of quantity of any kind at the quantum level

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

8. Group theory to the rescue?

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

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

11. The misleading use of "information" in physics

12. Despite all the unifications, the unification with the mind is not even on the agenda

13. The fundamentally reductionist orientation of physics

14. Why an 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

1. **The inherited fundamentally reductionist orientation of all natural sciences**

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

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

4. **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**
3. **The lack of a unifying basis for neuroscience and perception**
4. **The inadequate integration of perception in psychology**
5. **Why Chomsky's concept of generativity could not sufficiently influence the development of cognitive science**

Chapter 11

The false expectations of computer science

1. The logical origins of computer science

2. No commitment to a representation

3. Computation instead of information processing

4. The general search problem as a professional obsession substituting for ‘intelligent’ database organization

5. Why Google made it so big so quickly: Noticing the obvious

6. The amazingly immature development of artificial intelligence

Chapter 12

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

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

2. The importance of formative history: Developmental biology

3. Sheldrake's hypothesis of formative causation

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

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

6. Chomsky's concept of generative grammar

7. 'Structural' pattern recognition

8. The notion of emergence

Chapter 13

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

1. What should information processing be about?

2. The need to brake with the conventional, spatial, forms of representation

3. The basic structural units: Primitive events

4. The structural representation of a process: The (level 0) struct

5. The struct as a record of the formative history

6. The basic operation on structs: Struct assembly

7. The concept of structural constraint (at level 0) as a means of specifying a family of related structs

Chapter 14

The inseparable concepts of class and class representation

1. A single-level class and its representation

2. Level 1 structs

3. A two-level class and its representation

4. Level 2 structs

5. Higher-level class representations

6. An illustrative example

7. Some implications for developmental and evolutionary biology

8. One possible side of the emergence

Chapter 15

Transformations and representational stages

1. The macro-analogues of primitive events: Transformations

2. A multi-stage structural representation

3. Another possible side of the emergence

Chapter 16

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

1. The subjective struct as an agent's representation of an object and the objective struct as the Nature's representation of an object

2. The amazing unity of syntax and semantics

3. Some implications for science

4. The new radically simplified epistemology

Chapter 17

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

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

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

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

4. The structural measurement processes

5. Physics: From motion to information and structure

6. No need for the mysterious wave-particle duality

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

8. The new, structural, biology

9. No pyramid of sciences

Chapter 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**

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

Chapter 19

Conclusion: We are about to embark on our greatest adventure

1. But first, we need to learn how to use this new language

2. This is just the very beginning of a new scientific language

3. The new scientific outlook should catalyze the social transition