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HUMANS ON EARTH

From Origins to Possible Futures

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To my grandchildren Constança, Matilde,
Vicente, Frederica, and Sebastião

Foreword

Earth Systems Are in Trouble

"We are at a turning point," writes Filipe Duarte Santos, "as regards the essential resources of food, water, and energy. Demand already exceeds what can be sustained at current levels of consumption. [And] competition between states will be further increased by population growth and climate change impacts."

Professor Filipe Duarte Santos, a physicist and scholar of environmental sciences at the University of Lisbon, provides a sweeping, thoughtful view of the role of humans in shaping our modern world. Beginning with a short history of the Universe, he crafts an easily accessible narrative, weaving together an exploration of the laws of physics, an examination of human evolution, and an illuminating discussion of the roles played by art, religion, science, and technology.

Professor Santos' broad scope brings to mind the work of another physicist, Murray Gell-Mann, who opens his book, *The Quark and the Jaguar*, with the challenge: someone must dare to take a look at the whole. This author's discussion of Bayes' theorem (which enables us to improve our analysis of current situations by incorporating new evidence!) is particularly helpful as we look ahead to the major choices we face, especially regarding the means of generating energy. (The author serves on the United Nations' Intergovernmental Panel on Climate Change.)

As Professor Santos leads us through the era of human dominance, he concisely captures the collapse of civilizations and the social movements that challenged — and continue to challenge — established orders.

The discussion then brings us to a critical juncture: the conflict among *Homo sapiens* in World War II that also marked an acceleration of our conflicts with nature. In a poignant set of passages most relevant to today's world, Professor Santos discusses the Bretton Woods Agreements that were made in 1944 at the end of the war. These agreements marked a rare moment of clear-sightedness, with the implementation of new rules and institutions to steer civilization. (The changes in rules of trade were hammered out under the visible hands of John Maynard Keynes (UK) and Harry Dexter White (US), whose biographies are delightfully recounted in these pages.) The rules — 1. free trade in goods, 2. fixed exchange rates, and 3. constraints on the movement of capital — heralded a period of post-war prosperity. Their unraveling in 1971 gave birth to the modern period of unregulated finance.

In the closing chapters of Professor Santos' panoramic examination of our collective home, Western society's potential decline, paralleled by China's ascendency, emerges as a challenge to all. Can today's leaders reach new agreements that will protect humans and the planet?

Writing this foreword in August 2011, as world markets tumble and financial empires teeter, I can only hope we will choose a route similar to Bretton Woods, and consciously and collectively craft a new world order.

As with the Marshall Plan in 1946, today's world will need new funds to complement the governance structures that guide sustainable development. And, as the call rises from a growing number of Professor Santos' European neighbors — though not yet from the U.S. — the necessary funds would best be raised through levies on over-bloated financial transactions born of deregulation, rather than bled from financially-strapped nations.

With the health of forests, marine life, food systems, and humans threatened by mounting economic and environmental instability, the present book sets a well-lit stage on which to examine today's challenges for our powerful, though not always far-sighted, species.

Boston, Mass. *Paul R. Epstein, M.D., M.P.H.*
August 2011

Preface

The best of prophets of the future is the past

Lord Byron, Journal, 28 January 1821

Optimism is our duty. We are all co-responsible for what is coming

Karl Popper, Berlin, 17 December 1993

It is our privilege to live in an extraordinary age and to belong to an admirable civilization. Our skill, ingenuity, and determination over many centuries, supported by science and technology, have allowed part of humanity, mainly those who live in the industrialized countries, to enjoy an excellent quality of life compared with previous generations. We have easy access to modern medicine and health care. We have comfortable homes. We have good, drinkable running water, and a ready supply of energy to meet our everyday needs. We have a marvellous freedom of movement on land, sea, and air, and indeed prodigious mobility that allows us to move swiftly from one side of the Earth to the other. There are excellent conditions for reaching the various levels of education and professional training. Information and communication technologies have given us a remarkable facility of access to data, knowledge, and opinion. We are now able to communicate from practically every point on the globe with our families, friends, and colleagues. Generally speaking, we enjoy a good level of security, in our homes and urban areas. Most are convinced that all this has been permanently acquired and that in time it will spread everywhere and reach everyone in the world. We implicitly assume that continuous growth will assure social and economic development and an increasing quality of life for all. As regards the scarcity of natural resources and possible negative impacts on the environment, we are generally convinced that it will always be possible to substitute for exhausted resources and repair environmental degradation.

It looks like a dream. But will it last? Is it really sustainable? Those who do not yet enjoy such well-being are fighting desperately to obtain it. But will it be possible to extend the dream to the whole population of the world?

On the dark side, there are indications that the future is likely to become increasingly uncertain. Poverty, hunger, and serious health problems, such as tuberculosis, malaria, and HIV infections, persist in some parts of the world, and affect an unacceptably large number of people. The staggering social and economic inequality of the world's richest and poorest continues to grow. Over the last two centuries, human activities have begun to have a noticeable impact on global terrestrial systems, in particular on the climate, and also on the biosphere by reduction of biodiversity. The accelerating pace of human activity has created multiple and intertwined global challenges. There is a non-negligible probability that energy, food, and water crises may happen in the current century. The impact of unabated climate change, including rising sea levels and acidification of the oceans, environmental degradation associated with a fast-increasing world population that aims at rapid economic convergence, scarcity of natural resources resulting from increasing per capita use, rising resistance to antibiotics, nuclear proliferation, and international terrorism are examples of the serious challenges facing all of us today and in the near future.

On the bright side, since World War II, we have witnessed a remarkable acceleration in social and economic development worldwide, which has lifted hundreds of millions of people out of poverty and improved the quality of life of many more. This successful spike of global development has mainly been based on the increasing dissemination and application of science and technology, better political and economic structures and institutions, higher levels of production and consumption, increasing globalization through the integration of national economies into the international economy, increased mobility and migration, development of more robust energy systems, and increasingly widespread access to energy services. But what we must ask now is whether it will be possible to maintain this great acceleration in a sustainable way, especially as regards the environment and natural resources. How might we be able to do that?

There are various answers to these questions arising from different economic and environmental outlooks. Some emphasize that there are limits to our present growth paradigm and that we will inevitably encounter crisis if we disregard them. Others are convinced that we can overcome all the projected obstacles, and that our inventiveness and skills, supported by the development of science and technology, will always be able to solve collateral problems that may appear along our path to growth.

Beyond these different approaches, there is a broad consensus that humanity will face crucial challenges in the 21st century regarding the sustainability of its development paradigm. What is the nature and origin of this situation, and why are we experiencing it today? What is the role of science and technology in the relatively long process that has led up to it? What does science have to say about limits and about the future of our environment in the short, medium, and long term?

To answer these questions we must first look into the past. There is a profound and unbreakable link between our past, present, and future. Our current challenges and our ability to deal with them are largely determined by the essential characteristics of human nature, which were forged in the biological evolution that led to the emergence of *Homo sapiens*, and later in the ensuing cultural evolution. The presence of humans on Earth is of course an integral part of the history of the universe and there is no way we can divorce ourselves from it. There is no escape now or in the future from its fundamental physical laws. These are essential and pose insurmountable limits to our dreams.

In order to address our collective future and scrutinize our options, it is thus advisable to begin by reflecting upon and understanding our history. Science has given us the wonderful faculty to reconstruct, often with amazing detail, the past of our species, of life on Earth, and of the universe as a whole. The same scientific methodology has given us the possibility to project the long-term future of the Earth, the solar system and the universe. In this long process, the presence of humans on Earth is just a remarkable epiphenomenon. How sustainable is this episode and how long will it last? What are the driving forces that will determine its duration?

The main aim of the book is to focus on our present and future challenges as humans on Earth in the broad context of our cultural evolution and the unfolding long-term evolution of our earthly and cosmic environments. We are currently at a sensitive time as regards the impact of human activities on the Earth's systems. We may reduce the uncertainty and the risks projected into the future by creating a path of sustainable development. Science gives us the possibility to construct plausible and coherent socio-economic scenarios for the future. It is therefore possible in principle to choose between various options for the development of humanity. We may or may not respect the ethics of intra- and intergenerational solidarity. We may or may not create a future human development path that avoids irreversible environmental degradation. We may or may not increase the risks of future energy, food, and water crises. The following pages are an invitation to reflect upon these questions. They are an invitation to analyse and think about the past, the present, and the seeds that we are sowing for our common future.

The book presupposes that the methodologies of the modern sciences will allow us to observe, interpret, and understand the natural and social phenomena, and constitute a reliable tool to build a sustainable development paradigm. It is also founded on the conviction that the capacity of science and technology to solve our current problems and challenges is limited, whatever the realm of their application.

The present book is a modified and updated version of a previous one published in Portuguese by Gradiva in 2007.

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Lisbon, Portugal *Filipe Duarte Santos*
June 2010

Contents

Chapter 1

Science and Technology. From the Origins up to the Twenty-First Century

1.1 The Birth of Modern Science

The beginnings of modern science are rooted in a period of great conceptual development, which took place in Western Europe from 1500 to 1750. There were earlier origins, going back to the Greeks; Aristotle developed detailed theories of physics and biology, while Galen contributed to medicine and physiology, and Ptolemy to astronomy. They are coherent theories, based on a robust rationality that only began to slowly crumble when confronted with new facts arising from observation and experimentation. The initial development of modern science was a relatively peaceful process, if we ignore some extreme episodes of opposition offered by the Church, such as the burning of Giordano Bruno at the stake, or the persecution of Galileo. The process was led by a small intellectual minority, and passed largely unnoticed by the vast majority of the population. It was a highly discreet movement in the context of contemporary religious uprisings and the wars of reformation. Despite this contrast, science ended up deeply affecting the mentalities of future generations; even today, certain ways of thinking pioneered by science in the 16th to the 18th centuries still constitute a template for current scientific practice.

Perhaps the greatest legacy we have inherited, and which is now deeply rooted, is an eagerness to seek out relationships between bare and irrefutable facts and general abstract principles. We stress the importance of observation, experimentation, and a detailed analysis of natural phenomena, allied with the search for abstract generalisations that connect them.

In the origins of modern science, there is a new interest in observing phenomena and objects in themselves, stripped of their meaning and utility. It was necessary to develop a capacity to form the idea of an object just as it is, purely physical and devoid of all sensorial qualities. It was necessary to be able, through abstraction, to uncloak objects of their distinct qualities, rough or smooth, coloured or uncoloured, useful or useless, friend or foe. It was necessary to rethink nature in a geometrical form and reduce it to its physical properties. The physics of Aristotle is based on a doctrine characterised by ends, purposes, and meanings. This way of thinking

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together with the anthropomorphic concepts of nature fail to make sense in modern science. The behaviour of nature, ruled by universal laws and expressed by means of mathematical formulae, is inexorable and completely indifferent to man, to how he feels, and to his worries and anxieties.

This new vision had deep cultural consequences. The human experience became separated from the workings of nature, and this helped to open a conceptual path for the conquest and domination of nature. Only in the 19th and 20th centuries did we start to grasp the meaning of this domination, and to realise that in the end we are conditioned by deep ties of dependence on nature which we need to understand and preserve, rather than break.

The other essential characteristic of modern science is an instinctive conviction about the existence of an intelligible order in nature spanning all levels, from the smallest particle to the immensity of the cosmos. The initial belief in that order was not an attitude that resulted exclusively from an exercise in logic. It sprang from an intuition and a belief that proceeded to feed upon the successes of scientific endeavour, and particularly upon its predictive capacity. It could not be justified by inductive reasoning alone. It had its origin in the perception and understanding of nature's behaviour, revealed by observation and experimentation. The leading actors of the modern science movement from the 16th to the 18th centuries dared to believe in an intelligible nature capable of description through laws expressed in the abstract language of mathematics. For Alfred North Whitehead (Whitehead, 1953) this conviction resulted, in a subconscious way, from the insistence on the rationality of God, which was present in medieval European theology over many centuries. In other regions of the world, God was too impersonal, arbitrary, or despotic to imbue the way of thinking with a belief in logic.

1.2 Philosophy and Science

While for the Greeks science was a branch of philosophy, modern science moved slowly away from it, and became clearly separated in the 19th century. The relationship between them during this process was nevertheless very creative. In the 17th century, philosophical thought found, exposed, and explored various difficulties in the foundations and methodology of science. The philosopher David Hume (1711–1776) considers in his *An Inquiry Concerning Human Understanding* (1784) that each effect is an event distinct from its cause, and as such cannot be found in the cause. In other words, he denies the possibility of knowing causal relationships and considers that there are only connections between events, with no logical guarantee that they are not entirely arbitrary. In this form of empiricism, any rational foundation for prediction and determinism becomes impossible. According to Hume, the use of inductive inference, which plays a central role in the methodology of science, cannot be logically justified. In induction, we use propositions about objects or events that we observe and examine in order to reach conclusions about objects or events that we do not see and examine. Hume considers that this inference is only possible by assuming the existence of what he referred to as the 'uniformity of nature'. But then how could we prove that this theory is true? According to Hume we cannot, because we can imagine non-uniform universes subject to random changes in time. It would therefore be impossible to justify the validity of the inductive method in any rational way. Generations of philosophers have searched systematically for answers to the questions posed by Hume, and this continues to be an active area of research in the philosophy of science. However, and this is what is of most interest to us, these purely philosophical obstacles confronting the inception of modern science did nothing to hinder its evolution. In fact, they helped it to establish its own identity, independently of philosophy. Modern science did not seek to justify its intuitive faith in the intelligibility of nature. In the beginning, it was an anti-rationalist movement based on observation and experimentation that flourished at the end of the Renaissance.

But philosophy also contributed to clarifying and promoting scientific thought. Descartes (1596–1650) established a clear distinction between thought and the material objects of thought that constitute the various forms of matter. The thinking spirit is immaterial, has no extent, and is near to God. With this dualism Descartes created a place for God, a being that he considered absolutely perfect, defending himself against accusations of atheism, and freeing the sciences for the analysis of material objects stripped of their qualities, uses, meanings and symbolisms, that so strongly impressed upon the human spirit. In his *Discours de la Méthode* (1637), he proposes analysis as the privileged method for the spirit to search for truth in the sciences. Faced with a problem, we should break it down into its individual parts, reflecting upon and solving each one separately (which should be easier than treating the problem globally), and finally reconstructing the whole. This abstract methodology of analysis, later called reductionism, has nowadays become a basic habit of thought and constitutes the main instrument of scientific research. Its success is unquestionable.

The physical universe is described as a large set of dynamic galaxies formed mainly by stars made up of various particles including atomic nuclei and electrons, which may form atoms and molecules. The atomic nuclei are themselves made up of neutrons and protons, which in turn are made up of quarks. The structure and dynamics of the various entities on the different spatial scales are determined by the forces they exert among themselves. In one of these galaxies, there is a star with a planetary system in which one of the planets is Earth, built with the same physical entities, molecules and atoms, which in their turn break down into neutrons, protons, electrons, and so on. Reductionism does not apply only to physics, but to all areas of science. It is an essential strategy of science used to systematically explain the behaviour of complex systems that would otherwise be unintelligible. The physicist Steven Weinberg, a great defender and practitioner of reductionism, considers that the search for ever more fundamental physical entities and laws will eventually culminate in a final theory of everything in the Universe, when things cannot be explained in other more basic terms (Weinberg, 1993).

In this context the social sciences have a more balanced approach in practice, because they frequently use the methods of both synthesis and analysis. This difference has inspired some contemporary attacks on the methodology of science, some of which reach the point of considering that its dependence on reductionism constitutes a disorder of obsessive character, possibly indicative of a terminal phase. Nevertheless, we should recognize that the systematic application of abstract analysis that was clearly identified by Descartes in the years 1637 to 1649 and is now contested by some scholars has led to the enormous success of science and technology for more than three centuries.

The Cartesian philosophy has also had a profound cultural influence by contributing to the development of rationalism. This supports the conjecture that nature is governed by intelligible principles that can be reached through the use of reason to interpret the raw facts provided by observation and experimentation. In opposition to this, various lines of recent philosophical enquiry seek to devalue rationalism. They emphasize the absurd and meaningless character of life and claim an essential role for intuition, feelings, and faith, which cannot be reduced to reason. H. Bergson, S. Kierkegaard, M. Heidegger, and M. Marcuse are some of the influential modern philosophers that have contributed most to the analysis and development of such concepts. Where science is concerned, this opposition to rationalism stresses its limits as an expression of Western thought and resists the idea that it is the only path to knowledge.

1.3 The Universality of the Laws of Physics

The first big step toward the modern scientific vision of the cosmos was taken by Nicholas Copernicus (1473–1543) with his heliocentric model of the Solar System. There are records that lead us to believe that Copernicus became convinced of heliocentricism around 1510, but the defining publication — *De Revolutionibus Orbium Coelestium* — only appeared in 1543, the year of his death, and with an anonymous preface where it is stated that “these hypotheses need not be true nor even probable”, which certainly does not portray the opinion of Copernicus. For several generations many astronomers reading *De Revolutionibus* thought that Copernicus did not consider the theory that had consumed the greater part of his life as true from the standpoint of physics. The doubtful authenticity of the preface, which was apparently written by the Lutheran theologian Andreas Osiander, was known by a few astronomers but it was Johannes Kepler (1571–1630) who divulged it openly in 1609. These facts clearly reveal the difficulty at that time in affirming that the Earth was in motion: it was an affront to the church, the universities in which Aristotle’s model of the world was taught, and also to astronomers who used that model to interpret their observations.

Copernicus’s heliocentric model opened the way to the development of modern physics through the works of Johannes Kepler and Galileo Galilei (1564–1642). Kepler discovered that the orbits of the planets around the sun are elliptical rather than circular as Copernicus had thought, and he pronounced two further laws that determine the velocities of the planets in those orbits. Galileo, who was a great defender of the heliocentric model, used a telescope for the first time, and discovered many new facts, such as the existence of mountains on the moon, sunspots, satellites in orbit around Jupiter, and many more stars, all of which conflicted with the tenets of Aristotelian cosmology. However, his most important contribution was to use experimentation as a way to gain knowledge, namely in the study of mechanics, thereby establishing the empirical methodology as a route to understanding nature.

After Galileo, scientific development accelerated, culminating in the works of Isaac Newton (1643–1727), and in particular his main work *Philosophiae Naturalis Principia Mathematica*, published in 1687. The three laws of dynamics and the law of universal gravitation constitute a powerful conceptual base for describing the Universe as a group of particles and bodies in movement. Newton's theory was built with great mathematical rigour and demonstrated that Kepler' laws can be deduced from those of motion and gravitation. This was one of the first demonstrations of the universal and unifying character of the laws of physics that apply to Earth as well as to the entire Solar System. All these advances were made possible by the simultaneous evolution of mathematics, especially the analytical geometry of Descartes and the infinitesimal calculus invented independently by Newton and Gottfried Wilhelm von Leibniz (1646–1716). The rapid development of abstract mathematical thought served as the indispensable support to men of science in their quest to interpret the result of observations of natural phenomena and experimentations. With some surprise they concluded that there were laws underlying their observations and that these laws could be expressed mathematically. The mechanical vision of the Universe inherited from Newton constituted a conceptual framework for science for the next 200 years.

Scientists began to think that it might be possible to give an explanation based on mechanics for all physical processes in nature. This conviction was enhanced by the great successes of the mathematical physicists, which reached its zenith in the *Mécanique Analytique* of Joseph Louis Lagrange (1736–1813) published in 1787, one hundred years after Newton's *Principia*. With the publication by James Clerk Maxwell (1831–1879) of *Electricity and Magnetism* in 1873, almost one hundred years later again, the first cycle in the development of modern physics came to an end.

1.4 Determinism, Uncertainty, and Probability

By constructing a vision of the Universe in which everything can be described by laws of nature of a mechanical character, and always proceeding with mathematical rigour, the pathway to determinism was opened. Its initial and most eloquent expression is due to Pierre Simon Laplace (1749–1827). As he states in the introduction to his *Essai Philosophique sur les Probabilités*, published in 1814:

> An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the Universe and those of the tiniest atom, for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes.

The existence of such intelligence, sometimes called Laplace's demon, depends on two conditions: (i) a precise knowledge of the state of all systems that compose nature at a given moment, and (ii) a precise knowledge of the causal relationship between the different states of each of those systems. Twentieth century quantum mechanics invalidated the determinist concept, by proving that condition (i) does not apply in the realm of microphysics. The most frequent situation is a total impossibility to predict the result of a measurement of an observable in an atomic or subatomic physical system. The act of measuring interferes with the system, which responds by 'jumping', in an unpredictable way, to one of the possible final states. Apart from this lack of knowledge of a fundamental nature, the condition (ii) is, in most cases, impossible to put into practice on either the micro- or the macro physical scale.

This impossibility is clearly exemplified in chaotic dynamical systems, in which extremely small differences between various initial states produce very large differences in the corresponding final states. This hypersensitivity renders unpredictable the state of the system at a given moment in the future, since it is impossible to have accurate knowledge of its state at the initial moment. Note, however, that the assumption of indeterminism does not invalidate causality. Science discovers and uses causal relationships, but instead of being univocal, the same cause may produce various effects, with different probabilities.

This raises the question of the concept of probability involved in the relation between an event and preceding events. Sometimes, in a given situation, a conclusion about what will happen is almost certain, while in other situations, all conclusions are equally likely and therefore equivalent to no conclusion at all. The statement suggests that it may be possible to express the differences in the reliability of conclusions in a numerical form, by means of probability calculus. Thomas Bayes (1702–1761) was the first to believe in such a calculation, which according to him was necessary to justify inductive reasoning. The Bayesian theory of probabilities has evolved considerably since its origins and now has important applications in various areas of science.

One of the most interesting propositions of this theory is Bayes' theorem of inverse probability. Let us suppose that we have a theory X that predicts a result Y. The probability that the theory X is true when the prediction of Y is verified (called posterior probability) is equal to the ratio between the probability that the theory X is true (called prior probability) and the probability that Y occurs without presupposing X. The theorem leads to the conclusion that if the result Y in the absence of X is more unexpected then the theory X that predicts Y is more likely to be true. The usefulness of the theorem depends on our assigning prior probabilities with numerical values, and this may prove difficult. Bayesianism allows us to estimate the probabilities of predictions based on a given theory, and has given rise to what is called the Bayesian or subjective interpretation of probabilities.

The concept of probability is so important in contemporary science and technology that it is worth exploring further. Curiously, the first substantial work on the theory of probability was written by Laplace, who was a strong believer in determinism. This somewhat surprising connection is understandable if we bear in mind that, until the end of the 19th century, it was thought that the need to use probabilities was a result of our ignorance and not of fundamental and unavoidable uncertainties, as for instance the uncertainty that manifests itself in quantum phenomena. According to Laplace, probability is the measurement of a property of a sequence, namely, the relative frequency associated with the occurrence of a given event in that sequence. For example, the number of times one gets ‘heads’ when tossing a coin. However, to be a useful concept, the probability should have a value independent of the number of tosses. Therefore, we reformulate the definition and consider that the value of the probability is the limit to which the relative frequency tends when the sequence becomes infinite. This frequency or objective interpretation of probability presupposes an infinite sequence, which implies that we can repeat the same experiment under identical conditions with the same system, or that we have available an infinite group of identical systems, in each of which we can perform the same experiment independently and under identical conditions. In either case, it is impossible to run infinite sequences of experiences. We avoid this difficulty if we can find convincing arguments to attribute an a priori value to the probability of a determined event. Even so, the conceptual problem is not completely solved because the only way to validate the arguments used is to test the value attributed to the probability through measurements of the relative frequency. In conclusion, probability is not reducible to a measurement or a set of measurements. Ultimately, it expresses the relationship between two propositions — the probability of Y, given X. The nature of this relationship is related to the expectation that we have of finding Y, given X. This argument led various authors to consider a merely subjective interpretation in which the probability of an event Y is only a measure of the degree of confidence that we have in its occurrence, given X. According to Karl Popper (1902–1994), the probability, although subjective, has the capacity to reveal something objective about the outside world, which is the propensity of objects to behave in a certain way.

1.5 L’Esprit Géométrique et l’Esprit de Finesse, by Blaise Pascal

The development of modern science was one of the main forces at the origin of the Enlightenment, the intellectual movement that characterized a period of European history roughly coinciding with the 18th century. This was a cultural and philosophical movement of a rationalistic nature that proposed to ‘illuminate’ the minds of men with knowledge, obtained through science, and to free them from the darkness of ignorance, superstition, and obscurantism. Founded on a profound confidence in the power of reason, taken as the primary source and basis of authority, it exercised a systematic and critical analysis of laws, customs, institutions, politics, and religion, considered the most powerful and ever-present illusion.

The great success of science in the explanation of nature’s phenomena gave origin to the idea that the scientific method could also be applied to other dominions — history, sociology, psychology, archaeology, linguistics — and finish up constituting the 'science of man'. This doctrine, often called scientism, defends the idea that the methods of science can be applied to all the various realms of human experience and that, eventually, after the necessary investigations, it would resolve all uncertainties and controversies. The new crusade of science fed on the expansion of human curiosity to different areas of knowledge, the desire to achieve the unity and objectivity of an all-embracing concept of knowledge, and also the desire to benefit from the high social and intellectual status attributed to scientists in certain circles at that time. An example can be found in the publications of Karl Marx (1818–1883), when he defends the science of history as the only way to understand it. Every historical event should be analysed and interpreted in terms of the economic and social infrastructure that made it possible. According to this perspective, there is a 'mechanics' of history that allows one to predict its future scientifically.

Scientism is based on the belief that the scientific method has a practically unlimited power to interpret phenomena, whatever their nature. There is something fallacious in this argument, because science is based on abstract analysis leading to laws of a quantitative nature whose logical consequences are susceptible to being tested against observation and experiment, whereby they are either rejected or confirmed. However, there are vast dominions of human experience that are impenetrable to abstract analysis.

It was Blaise Pascal (1623–1662) who, for the first time, laid the foundation for that discussion by identifying two fundamental types of temperament and modes of thinking: the geometric spirit — *l'esprit géométrique* — which comes into play when we are dealing with exact definitions and abstract concepts in mathematics or science, and the intuitive spirit — *l'esprit de finesse* — when we are dealing with ideas, perceptions, and feelings that cannot be expressed by means of exact definitions. For Descartes, intuition was the foundation of rational knowledge, but for Pascal it constituted a faculty irreducible to reason, and which, in the final analysis, makes it subordinate in all dominions where it is used. Mathematical reasoning is incapable of learning or understanding the contradictory character of human experience, which lies outside the scope of scientific knowledge. This kind of knowledge is expressed by propositions that will be accepted or rejected in accordance with a specific and consensual methodology. It is understandable that we should try to generalize as far as possible the application of a methodology that leads us to consensus and even unanimity. However, there are other kinds of knowledge, besides scientific knowledge, that come from the 'intuitive spirit', and whose contents are not susceptible to being accepted or rejected via a consensual methodology. Recognizing this limitation is an important step towards developing the necessary tolerance and understanding to face the most diverse conflicts in human society.

Pascal's genius and life experience provided him with unique conditions to illuminate the distinct qualities of intuition, sentiment, and reason. He was a noted mathematician: at the age of 15, he published an essay on conics read by the leading mathematicians of the day, including Leibniz, and later wrote studies on combinatorics, calculus, and probability. He was also a physicist: from the age of 23, he experimented with vacuum and observed the variation of atmospheric pressure with altitude. He was also the inventor of, among other things, the hydraulic press, the syringe, and a mechanical calculator, called the Pascaline, which was the first prototype of the computer.

With an active intellectual, social, and emotional life, he experienced a deep mystic call and converted to Jansenism in 1655 at the age of 32, living among the ‘Solitaries’ of the Port Royal Abbey. He intervened in the theological quarrel between Jansenists and Jesuits, by writing *Les Provinciales*, which enjoyed enormous success at the time and went on to become the literary model for modern French prose. Later, he abandoned the fray, and conceived of a project of apology for the catholic religion directed at libertines and atheists. However, he only managed to write a few notes, published posthumously under the title *Pensées*, which constitutes his best known and most influential work. There, the distinct faculties of the ‘spirit’ are clearly characterized, providing a way to disprove the tenets of scientism and to circumscribe the limited achievements of science in the explanation and guidance of human life.

1.6 The Evolution of the Species

In spite of these limitations, later on in the 19th century, science succeeded in identifying the mechanisms of the evolution of life since its origins. This discovery resulted from the patient and systematic observation and analysis of natural phenomena in conjunction with a quest for the abstract laws that relate them, following the most exemplary tradition of scientific methodology. The observations were made by the young biologist Charles Robert Darwin (1809–1882), over fifty seven months on board the H.M.S. Beagle, particularly in the Madeira and Galapagos Islands and along the western coast of South America. The great diversity and mutability of the flora and fauna on the islands led him to postulate that the species evolve as a result of a natural form of selection that favours mutations better adapted for survival. His book *On the Origin of Species*, in which he expounds this theory, published on 24 November 1859, sold out in one day, and raised the most violent reactions. The Church led the opposition, as the concept of natural selection would force one to abandon the creational thesis of the Bible, and implies the absence of a divine finality or intention in nature and all its diversity. Nevertheless, Darwin’s ideas were successful, and exercised a strong influence not only in the realm of science, but also in philosophy, religion, psychology, anthropology, sociology, and politics.

Since we are programmed to deal with processes that can take anything between a few seconds and a few decades, we have difficulty in understanding the mechanisms of the evolution of species, because they result from cumulative processes that are extremely slow, typically taking tens of millions of years. The mutations in genetic material can generally be put down to chance, but only a few achieve relevance in evolution, due to the implacable process of natural selection, whereby in each generation, the individuals least adapted to prevailing conditions are removed from the population. The combination of these two mechanisms generates an evolution driven by adaptation to an external environment in permanent change. Apart from this property, it is completely without purpose or finality. According to Stephen Jay Gould there is no evidence of any privileged direction for the evolution of species, and none of its products, such as *Homo sapiens*, could be considered as inevitable. If it were possible to repeat the 'programme of life' a million times since its beginning on Earth, that peculiar simian with a relatively large brain would never reappear (Gould, 1989).

Although Darwin formulated and developed the theory of evolution strictly within the field of biology, several currents of thought tried to apply it to ethics and the social institutions in the latter half of the 19th century. This movement, known as social Darwinism, arrived at various conclusions, some very controversial, such as the idea of using natural selection to defend a social concept that legitimises the inevitability of social inequalities. This was another example of scientism. Here it was necessary to return to the scientific method and make systematic observations of the behaviour of living organisms to find out to what extent their social behaviour had a biological foundation. This work was undertaken by Edward O. Wilson, who published it in *Sociobiology: The New Synthesis* (Wilson, 1975), based notably on a description of the social behaviour of various animals from ants to antelopes and baboons. Only in the last chapter does he mention sociology, and consider the possibility of turning it into a scientific discipline, asking whether it is possible to subsume it under the Darwinian paradigm. This is an important question, still open, lying at the boundary of science's applicability.

1.7 Symbiosis Between Science and Technology

Since the very beginning, science has had a partner which had already been around for a long time before science came on the scene — technology, or more precisely *techno*, the Greek word for skill, craft, or practical art, without the 'logy', which implies study and the use of reason. The history of technology, in the widest sense, starts with the fabrication of rudimentary artefacts by Hominids, more than two million years ago. The appearance of the first tools in chipped stone, around two and a half million years ago, occurred during a period of large increase in brain size (Leakey, 1994) that led up to *Homo sapiens*. Since then technology has developed prodigiously through a multiplicity of ever more complex inventions, which have in turn led to further innovations that have profoundly transformed human society. Nevertheless, according to Freud (Freud, 1929), technology continues to represent, in its essence, an extension of our limbs and organs that allows us to improve our capacity to act, that is, a means to an end.

In its origins, objectives, and methods, science is clearly distinct from technology, but has benefited from it at the outset. On the other hand, technological innovation has frequently used, in an empirical way, properties and mechanisms that only later became fully explained by science. A revealing example is the water pump, invented and used long before Evangelista Torricelli had measured atmospheric pressure in 1643. Once we were able to get water to rise in a tube with a piston, it was said that nature abhorred the vacuum, but this did not explain the fact that it was quite impossible to get the column of water higher than 10.3 metres, which corresponds to the atmospheric pressure of one atmosphere (1.103×10^3 Pa).

Another example is the steam engine, invented by James Watt and Matthew Boulton, and used in the English textile industry with great success around 1785. The conception, construction, utilization, and commercialization of these machines happened long before the fundamental laws of thermodynamics were discovered. On the other hand, steam driven machines played a very important role in science, because many of the ideas that led to thermodynamics had their origin in the study of the way these machines worked. James Prescott Joule established and measured the equivalence between mechanical and thermal energy only in the 1840s. Around 1851 William Thompson, better known as Lord Kelvin, formulated the second law of thermodynamics, which established the efficiency limits of heat engines. In this case, as in many others, the construction of instruments and machines of great practical value preceded the complete scientific explanation of the processes used. The precedence of practice over theory can be seen not only in science but also in the arts, and it reveals an important characteristic of the creative processes of the human spirit.

The case of James Watt reveals yet another facet of the symbiosis between science and technology. Very early on, he showed great capacity for mathematics, a keen interest in the works of Newton, and an uncommon ability for mechanics. The University of Glasgow employed him as an instrumental technician with the title ‘instrument maker to the university’. There he benefited from contact with the science of the day, and especially from acquaintance with Joseph Black, a professor at the university, and one of the pioneers of the study of thermal processes. Called upon to repair an exemplar of a primitive steam driven machine invented by Thomas Newcomen, which belonged to the university, he became very interested in the project and ended up constructing a much more efficient steam engine, thereby becoming one of the most famous mechanical engineers of Scotland. For James Watt, passage through the university was a source of scientific knowledge and inspiration. The construction of the new steam engine was only made possible through a focus on innovative technology, practical skill, and an ability and experience in instrumentation.

Science benefits from and depends on technology because of its fundamental contribution to developing new means of observation and experimentation. This dependence of science on instrumentation has evolved greatly since its origins. Notable examples of such evolution are the telescope and the particle accelerator. We consider the former to have been invented (as far as we know, accidentally) in 1608 by Hans Lippershey, a Dutch optician. In the same year, the instrument, consisting simply of two lenses at the ends of a long tube, was presented to the government in The Hague, and the Captain General of the United Provinces and other high dignitaries were puzzled to see the clock in Delft and the windows of a church in Leiden. It was an immediate success that spread rapidly throughout Europe. In the spring of 1609, Dutch merchants took it to the north of Italy, where in May Galileo saw it and decided to make an improved version. The observations made by Galileo with