SCIENCE, SOCIETY AND THE EVOLUTIONARY DRIVE

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Preface:

The Main Message of this Monograph

Charles Darwin conceived his evolutionary hypothesis in the years 1837-42, though he delayed the publication of his "On the Origin of Species by means of Natural Selection" [1] till 1859, with A.H. Wallace meanwhile joininig in with his version in 1855 [2], their joint communication appearing in 1859 [3] and H. Spencer's philosophically oriented contribution in 1864.[4]. After several decades of unsuccessful attempts to provide the theory with a precise and predictive mathematical formulation, his thesis started acquiring a structural interpretation towards the end of the century, when G. Mendel's (1865) discovery of {\it genetics} [5] had matured enough to be fully exploited., It reached its full development around 1945, with the advent of {\it molecular biology}, spearheaded by such as E.Schroedinger [6] and L.Szilard [7], culminating in 1957, with the discovery of the {\it genetic code}[8].

Darwin's theory was offered as an explanation for the existence of the species making up the living kingdom, classified by Karl von Linne' ("Linneus") [9] in the XVIIIth century (and of the vanishing of other past biological species, whose traces are found in the geological record). With the present knowledge of the precise mechanism of mutation, biological evolution has indeed become a "routine" science, in that it may be experimentally verified, whether in the laboratory, in the field -- or in computer simulations.
The idea was soon borrowed by other fields -- and a "*Generalized Theory of Evolution*", covering all levels and stages of reality, began to crystallize, even before the experimental validation of that biological model; so much more so, with the availability of a *complete* theory of *biological* evolution. This further spurred the search for a similar understanding of evolutionary processes in additional realms of reality, both physical and spiritual.

This *Generalized Theory of Evolution* identifies and traces processes of an evolutionary character , occurring everywhere, generating ever-growing *complexity* in every domain of reality. Their domain of applicability extends from the somewhat speculative *cosmogonies*, [10-12] i.e. hypothetical processes involved in the *creation of universes*, partly through *anthropic* constraints on the range of values of the key parameters -- to *nucleosynthesis*, i.e. the making of the observed chemical elements [13-16] with their condensed astrophysical macroscopic cumulates, while also triggering the Darwinian processes generating the biological species, -- with, ever since the arrival of the human species, evolutionary processes in *social anthropology* [17-18] and furthermore, in the growth of *ideas*, be it in the formation of the human *ethical* code [19] or in the making of *science*, namely in Epistemology.[20-28]

This book is an attempt to reformulate that Generalized Theory of Evolution in terms of a more precise and logically complete paradigm, replacing today's half-hazard compilation. The model is still the biological case, as it is the best understood at all relevant levels and stages, from the genetic code to zoology, botanics, ecology or paleontology etc. We then apply the new paradigm to various evolutionary sectorial sequences, gaining new insights. For the academically-oriented reader who is otherwise familiar with the existing literature, I have marked with an asterisk those seven topics in which I believe he/she will find basically new material.

The book is organized in 4 parts.

Part I develops the Generalized Theory, starting with the original and best known *biological* (Neo-Darwinism) case, again as our model, after which I review the evolutionary treatment of the earlier stages in the chronological sequence – cosmogony, nucleosynthesis and the emergence of life. In biology, we have a rather complete picture, with the molecular biology DNA realization of the *genetic code* as a *cybernetical program* undergoing a repeated reproduction process, a routine which exposes the program to
random mutations, which I shall denote as "type P" mutations. The mutated program and the organism it serves then undergo a *natural selection* "filtration" mechanism – Spencer's *survival of the fittest* .

Modern Paleontology, however, has uncovered massive *extinctions* of hundreds of thousands of species occuring during the transition periods corresponding to the border layers between geological eras, with the evidence indicating that this is generally the result of catastrophic events such as meteors [29], comets or asteroids colliding with the Earth. This is then clearly another natural strategy in the evolution of living species – *survival of the luckiest* **--** and a new opportunity for nature's "*scalawags"* , i.e. formerly marginally subsisting species, now flourishing, once the dominant species have been badly hit. This is how the mammals got their chance after the demise of the dinosaurs.. A modern theory of biological evolution has to face and digest these facts. I view *Extinctions* as *catastrophic mutations of the environment** [27-28], which we shall denote as "*type* EC" mutations, instead of the usual case where they occur in the system's cybernetical program (here DNA). Seen from the organism's angle, the extinctions represent *catastrophical passive* mutations*, as against the directly *active* features of the ones occurring in DNA ("type P"). As a matter of fact, the extinctions are *massive*, *catastrophic* mutations of the environment, but we should now also notice the existence of milder mutations of the environment, such as the emergence of a *new predator* . In some cases this predator is human – hunting for fun or to sell furs – or building a dam over the river where our specific fish lives. As a matter of fact, *graded mutations of the environment* are a natural feature of the evolutionary process, as it operates simultaneously on all species sharing one environment. These will be denoted as "*type* Eg" *mutations* of the *environment*. For the algebraaically inclined reader, Eg and EC mutations respectively correspond to the linearized infinitesimal variation and the finite integrated one in the action of a Lie group.

I then sketch the outline for a *generalized evolutionary paradigm**, with three entrance-channels for *tychic* intervention (Tyche is the Goddess of luck in Greek Mythology), generatimg random mutations of the three types. This incorporation of the catastrophical massive extinctions and of the graded modifications of the environment in the evolutionary paradigm [27-28] represents two of the seven main innovative contributions I present in this book. Another original contribution at the level of the Generalized Theory of Evolution relates to the notion of *Complexity** [30-31]. In chapter 4, I draw a lesson in the physics behind this notion from the latest results in Quantum Gravity and the physics of Black Holes [32].   .

Part II deals with *Evolutionary Epistemology*. I present two original contributions, consisting in a precise determination of the mechanism realizing types P and EC tychic intervention in Epistemology. Type P are realized by *Serendipity** (an approach developed with A. Kantorovich [22]), while *Invalidation** (Popper's "*falsification*") acts for the type E tychic *massive* (or catastrophic) intervention [27-28]. The analysis in terms of the evolutionary paradigm also throws additional light on this *double* character of the evolutionary role of *scientifuic research*, namely, the evolution of the science itself, and that which we discuss in Part III, namely that of the human societies it serves and drives, as its main channel for tychic type P interventions, essential to any evolutionary sequence [17-18, 24-25].

Part III deals with "Progress*" [17-18], i.e. the evolution of Society.
Since the appearance of man, biological evolution has, in this context, been mainly replaced by {\it social} evolution.

Qualitatively, the mechanism relies on the same principles, i.e. random "mutations" and an effective selection through the stability of some of the transformed states. Here, cultural and educational values replace the genetic code, in controlling the behavior of human societies. From time to time, a more advanced culture evolves. These are the "stable mutations", the new rungs in the development of human societies, and they are characterized by new {\it technologies}, e.g. the Paleolithic, Neolithic (to start with, the technology related only to hunting tools, i.e. weapons, but it then ushered in agriculture), or the Chalcolithic, the Bronze or Iron Ages, or, closer to us, first the Industrial and now the Information Age, or the Age of the Computer. Where then does the {\it randomness} feature appear in this part of evolution? My thesis is that {\it it enters through the process of scientific and technological innovation} -- in modern times this is {\it research}. {\it A truly innovative discovery has to involve results which could not have been preplanned or even expected.} For the evolution of human societies, this is the main, but not the only message. We shall also observe *graded* mutations of the environment, except that they will mostly contribute *positively*, e.g. when some evolutionary process that failed previously now becomes possible because of a newly available technology, an *enrichment* of the *technological* environment The "new predator" of the biological environment is the common result of parallel evolutionary streams; in technology, parallel streams generally mutually enhance the potential results. The two major examples in PartIII which I treat in detail also provide illustrations of this:feature. The discovery or invention of the magnetical compass in China in the XIIIth Century enabled Columbus and others in the XVth Century to sail straight through the oceans, whereas Eric the Red and Leif Ericson had to take that Iceland-Groenland-Labrador route, constrained as they were to coastline sailing. In the history of the computer it is the development of vacuum tubes and electronics that created conditions for the aabstract Turing machine to materialize as the modern computer whereas for Babbage's ideas to materialize would have required having a kilogram-weught of heavy gear-wheels for every centigram of the modern machine.. .

Part IV deals with an issue in which genetic evolution overlaps with the evolution of society. I believe I have derived some useful insights from the notion of a *generalized* evolutionary paradigm as against the implications of a restriction to Genetics and the Darwinian paradigm uniquely. The issue is that of Ethics *[19] I refer to the {\it stability /fitness} issue in the evolution of society, analyzing specifically the evolutionary advantages of {\it altruism}, generally considered as the principal contribution of the Judeo-Christian dogma. An important point here relates to the distinction between the genetic and the educational spheres in the cybernetical apparatus.

In the fall of 1996, I gave a series of lectures in Jerusalem, at the Van Leer Institute, covering all the above phases and topics. I am grateful to the Institute Director at the time, Prof. Levzion, for the invitation to give that series and to Mrs S. Sorani, the Institute editing director, for recording the lectures and for a first editing of the transcript. From those transcripts, I edited a book in Hebrew "Order out of Randomness – science and human society in a generalized theory of evolution" [26]. In the late spring of 1999, I gave a similar, though somewhat extended series at the Center for Technological Education at Holon (CTEH), in the framework of a Program dealing with the interface between Science, Technology and Society – a subject for which the CTEH plans to develop a specific expertise.. The present volume covers the material I gave at Holon, except for the incorporation of the extinctions in the new version

Each of the book's four parts is preceeded by a personal introduction explaining how I came to deal with the topics it covers and providing some general comments

My wife, Mrs Dvora Ne'eman, has heard me develop these ideas since 1977 and has provided many valuable criticisms, sometimes of the message, more often of the presentation or delivery. I owe her many thanks and indeed dedicate the book to her.

I also thank several friends – all biologists – who have acted both as a *sounding board* for some of my ideas,throughout their growth and crystallization – and sometimes as my guardiens as against errors in my understanding or inmy

remembering the details of some biochemical reactions:
Professors Ephraim Katzir, Alex Keynan, Renana Leshem-BenGurion and Michel Revel. I owe particular thanks to my friend and sometime partner in the political struggle, Rabbi Eliezer Waldman, Head of the Nir Yeshiva in Hebron, who introduced me to the writings of Palestine Chief Rabbi (in the early XXth Century) Abraham haCohen Kook (_) and especially his chapters on Evolution - and to my physicist friend Professor Cyril M. Domb, FRS, who acquainted me with the writings of Rabbi Menahem M. Schneersohn (-), of the Habbad movement, on the same topic. I also thank Dr Michael Shai Cherry for sending me a copy of his Brandeis University doctoral dissertation.

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Part I: Generalized Evolution and the new Paradigm

Introduction

The ideas which appear in this book sprouted in the back of my mind during the thirty years in which I was doing research in physics, or sometimes in connection with the various positions I have held in directing research programs at the institutional or at the national level. My basic views as to evolution began to crystallize at an early stage in my development as a professional researcher; the subject excited my curiosity and I read various classics -- until I encountered and read Jacques Monod's (1910-1976) "Le Hasard et la Necessit{\'e} [33]". Monod presents a definition of {\it life} inspired by modern Neo-Darwinism and genetics, to which he himself had made important contributions. I noticed that Monod's definition and characterization of life could just as well describe the "life" of a star or the growth processes of a crystal. I wrote to Monod and pointed it out to him. From then on, I was always on the lookout for such characteristics common to {\it dissipative} processes, wherever I would come across new examples of such phenomena -- from astrophysics and cosmology to anthropology. Gradually, a coherent generalization emerged, bringing together the results from the individual fields -- the view I present in Part I of this book.

We shall show that all evolutionary processes share -- almost by definition -- the following features:
(note: Tyche is the goddess of Luck in Greek mythology)
1.A *population* N of *systems* (or *organisms*) $S_{i}, i=1…N}$ existing and operating in an *environment* E: $S_{i} @ E$.
2. The system's operation is controlled by a cybernetical *program* P^{i} storing information and controlling the *construction* and *operation* of each of the above systems individually.
3. This program has in addition to undergo a *tyche-vulnerabilizing routine* R opening the way for *tychic* interventions T (i.e. random disturbances) to occur sometimes.When they do occur, they produce random modifications in the original program $T.R.P^{i}->P^{i}'$, wheraes $T.P=P$.
4.The system with its modified cybernetical ;program then undergoes effective testing F of its *selective stability criteria*, determining which of the modifications are "good", i.e. (a) capable of staying on in the program, $F.P' --> P'$ and (b) enhance the organism's *chances of survival* $F.S' -→ S', Q(S')> Q(S)$. Q provides a measure of the *chances of survival*.
5. In other words, as most mutations result in the creation of defective and unstable systems $Q(S) > Q(S')$, generally without continuation $Q(S"")→0$, yet on some occasions a stable, and thus also permanent, new system is generated, thereby constituting a new rung in the evolutionary ladder. This is then a "type P" (active) *mutation*
6.. An alternative mechanism - effectively a *passive* mutation - occurs when instead of the *program* mutating, it is the *environment* which has undergone a change, as a result of which the stability criteria

have been modified and the previously selected cybernetical program fits no more. We shall designate this mode of operation as a {\it type E (for “environment”}) mutations}

The identification of this alternative mode and my way of incorporation it in {\it a new evolutionary paradigm} is one of the main innovations I present in this book. It has become essential because of the discoveries of *massive extinctions* of hundreds of thousands to a millionn bio-species in the transitions layer between any two geological eras. but I shall demonstrate that it also resolves a major riddle in the logical structure of Evolutionary Epistemology., removing an apparent clash between the two most important contributions of epistemologist Karrl Popper, namely Popperian *Invalidation* (sometimes named “falsification” [34]) on the one hand and Popper’s Evolutionatry Epistemology” [20] on the other hand.. The evolutionary impact,of the catastrophic mutations of the environment sometimes occurs via

7. These catastrophic mutations are not the only kind of mutation undergone by the environment. In principle, considering the fact that in almost all cases the System S is not alone and not the only species in that environment. When an environment is shared by many species, we can expect our subject, namely the species S, from time to time to face the emergence of a new predator, thereby affecting the chances of survival for S, either slightly, because of competition ((if S itself is also a predator) or more heavily (if S is defenseless and thus a prospective victim). The inverse mutation – the emergence of a prospective new item in the environment’s fodder inventory. All such cases represent *graded mutations of the environment* .

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{\bf Part I: Generalized Darwinian Evolution}
\vspace{.3in}{\bf Chapter 1. Biological Evolution}
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\noindent
{\bf 1.1 Darwinism at birth}

The doctrine of evolution was launched in 1859, with the publication of Charles Darwin's book {\it "On the Origin of Species by Means of Natural Selection"}. Charles Robert Darwin (1809-1882), to quote his full name, as a matter of fact almost "missed the boat", in his continuous procrastination, a result of hesitancy and perfectionism combined . It seems he might never have issued his {\it magnum opus}, had it not been for the very special set of circumstances which developed in 1858.

Darwin came from a very favorable background, both intellectually and economically. Very roughly, his father's family provided the intellectual platform, with the grandfather Erasmus Darwin, an important physician and theoretical naturalist, whose ideas already included a foretaste of the future theory of Evolution. Robert Darwin, Erasmus' son and Charles Darwin's father, was also a well-known physician. No wonder, therefore that following a rather classical education at school, Charles was sent at sixteen to study medicine. He did not like it (he could not stand the sight of people suffering pain) and decided instead to study at Cambridge, with the intention, after the usual three years of general studies, of joining a Seminary and joining the Ministry.

Charles' mother was the daughter of Sir Josiah Wedgwood (1730 – 1795) , founder and owner of the famous Wedgwood porcelain pottery factory – so that the economic aspects of the family were considered to be well taken care of on that side – a fact which had its importance at a crucial stage, as we shall see in the sequel.
{{}^{*}}{\footnote{{}^{*} The firm still exists in 2,000 (one can visit the museum with their ceramics at Hanley, in England) – so does the dynasty. The most prominent member in the XXth century has been the British Labour Party MP Josiah Wedgwood (1872 – 1943), first Baron Wedgwood, who throughout his entire parliamentary career (1906 – 1942) was the staunchest (and sometimes the only)
British supporter of Zionism and of the activities which led to the creation of the State of Israel – an attachment which he formed after fighting at Gallipoli with the men of the Zion Mule Corps at his side, commanded by Joseph Trumpeldor, the Zionist hero.}}

Charles Darwin had displayed an early interest in collecting and organizing – plants, minerals, coins, etc. Such activities occupied him from the time he was eight years old. Now on his own at Cambridge, he developed these activities (at this stage he collected mostly beetles), with this having the effect of bringing him to the attention of the Professor of Botaniy, John S..Henslow, and starting a friendship between the two. Furthermore, Henslow arranged for Darwin, during his last summer at Cambridge, to accompany Adam Sedgwick, the Professor of Geology (and one of the founders of modern Geology) on a field trip to Wales. In 1831, upon his return home after this trip -- and having terminated his general studies at Cambridge - Darwin found a letter from Henslow, now offering him the position of naturalist to an expedition – the voyage of H.M.S. {\it The Beagle} in the Southern hemisphere. The position had originally been offered to Henslow, whose wife, however, strongly objected to a several-years absence on his part; he had then offered it to his naturalist brother-in-law – who finally declined -- and he assumed he could recommend a serious student-collector such as Darwin. The position carried no salary – except that Darwin would be allowed to sell any specimen he would bring back from the trip. Charles wanted to accept the offer, but his father objected, especially since this seemed to represent a one-time occupation, with no future profession or position following the trip. Robert Darwin challenged his son, promising he would only change his decision if Charles would find one "sensible" person who would support the idea It was at this juncture that the Wedgwood social position saved the day: Charles consulted his uncle Josiah Wedgwood II (who as a prominent businessman certainly fulfilled the requirements from a "sensible" person). To Robert's surprise, Wedgwood liked the idea very much and pleaded the case with Darwin-senior, arguing so strongly that Robert finally gave in. .

The Royal Navy's H.M.S. {\it The Beagle}.was setting out on a voyage of exploration in the southern hemisphere, due to last several years. The main aim was to study the fauna and flora of the least known regions, with the ship's naturalist noting down all the botanical and zoological data from the observations, collecting specimen and classifying them -- in other words, his was the responsibility for reporting the scientific results of the expedition. Darwin kept notes on all aspects of the voyage and published shortly after their return the detailed story of the trip in a book {\it "The Voyage of the Beagle}, a travelogue which attracted attention and achieved notable success. The trip had lasted five years.

It was during that trip and as a result of his comparative studies that Darwin perceived an emerging pattern and conceived his theory. He had taken with him the first volume of Sir Charles Lyell's {\it "Principles of Geology}, one of the first books which dared dispute the Biblical story as to the Earth's age. Reading that book and studying the paleontological evidence enabled Darwin to overcome any prejudice he might hsve felt for the literal interpretation of the Creation story in Genesis. However, aside from botanical, zoological or mineralogical specimen, Darwin also managed, on that trip, to catch {\it Chagas' disease}, an Argentinian variant of the African {\it Sleeping Sickness}, a debilitating malady from which he suffered throughout the rest of his life. He received good and loving care, from his wife and cousin Emma (Wedgwood), whom he married some two years after his return from the voyage of the Beagle. Emma also brought them a dowry which made it possible for the couple and their gradually increasing family (ten children!) not to depend on Darwin's salary of the moment. In the first three to four years after the marriage, Darwin served as Secretary of the Geological Society and developed friendships with the most important scientists in related fields, among them Sir Charles Lyell (whose book had so influenced him on the trip) and the botanist Joseph Dalton Hooker. In September 1842, Darwin moved with his family to Down, in Kent, where he stayed in quasi-seclusion for the rest of his life.

Between 1837 and 1842, Darwin organized his material and composed a condensed version of his evolutionary thesis, something we would qualify nowadays as an "extended abstract", which he showed only to a few friends and experts – such as Lyell and Hooker --.experts whose criticism he valued. Progress was very slow until 1856, when, as a result of pressure by Lyell, he began to write the full text – a treatise presenting the ideas of evolution, together with all the evidence he had in its favor. This he again showed, piece by piece, to his geologist and biologist friends. Draft followed draft, with a few selected biologists again commenting each time -- and Darwin procrastinating. One day in 1858, he received a manuscript with a forwarding letter from Arthur Russell Wallace, a young researcher on a field trip in Malaysia, who had independently reached conclusions very similar to Darwin's and was now on the verge of publishing a "theory of evolution".. Darwin's colleagues and friends, Lyell and Hooker, intervened and told Wallace about Darwin's ideas and drafts, finally managing to convince him to replace his article by a joint publication by the two men, thereby averting a priority dispute. The elegant solution preserved Wallace' s rights without denying Darwin's. The lesson was effective and made Darwin finalize his draft, the book appearing at last, some time after that joint publication.

The Darwin-Wallace papers appeared in the 10 August 1859 issue of the {\it Journal of the Proceedings of the Linnaean Society}, following a joint presentation by the two scientist-authors before that society. The papers consisted of four items: (a) an extract from an unpublished paper by Darwin, (b) a letter of Darwin's to Asa Grey at Harvard, summarizing the evolutionary hypothesis as conceived and viewed by Darwin; Wallace's paper; and a covering letter by Hooker and Lyell.. .

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{\bf 1.2 The Scientific Method : from Phenomenology to Regularities (such as a classification) and then to Structure and Dynamics.)

That the platform was provided by the Linnaean Society appears to me very appropriate. One reason Darwin (and Wallace) could conceive of evolution was that they were benefiting from the existence of a recognized {\it general classification of the known species in the vegetal and animal kingdoms}. It had been launched and developed by the Swedish naturalist Carl von Linn\'e (1707-1778), also known as {\it Linnaeus}, in the Latin used by all European scientists before the XVIIIth century and by botanists to this day. Various naturalists -- mostly herbalists -- had attempted in the Middle Ages to construct such a classification - with relatively meager results. Linnaeus, however, followed in the footsteps of several XVIIth century physicians, who had exploited the invention of the microscope, e.g. observing such details as cells, for instance. These researchers had performed anatomical dissection, experimenting, observing and measuring -- rather than blindly believing Aristotle and treating his writings as sacred scripture *${}^{*}\begin\footnote::{this was a stupidity for which Aristotle is not to blame, he was a true scientist and did not proclaim that he had all the answers. It was the Church, in the Fifth Century A.D., which, while combating the last Neo-Platonists and their residual scientific activities, "plugged" the intellectual hole created by their elimination with a {\it de facto} addition of one of Aristotle's less brilliant and least scientific books, the {\it "Organon"}, in a Latin translation. to the Christian canon} {\end\footnote}$ By the end of the XVIIth Century, a vast amount of experimental material had thus accumulated and Linnaeus now succeeded in ordering it and applying the results to identify a pattern of classes, orders, families, sub-families, genera and species. Note that his classification was advanced enough to assign seals and whales to the mammals and put the monkeys, apes and man together in the order of {\it primates}.

With this ordered list before him and his own observations in the voyage of the Beagle, Darwin could now ask the relevant question "how did this order come about?", rather than the vague "how were the plants and animals created?" which had at best led to the answer in Genesis -- "by a creator" -- which, even taken to be true, certainly does not explain the mechanism He/She used.(we shall often encounter the interface with religion, in this work -- and discuss it somewhat more in depth in the coming sections).. Hypothesizing that
under some environmental constraints, transitions (our present {\it mutations}) could occur between neighboring squares in Linnaeus' chessboard, Darwin could now also conceive that this creation might have taken place continuously and in steps, with each species arising as a modification of a previously existing one. The whole system might thus have started with the most primitive organisms, the monocellular ones. The evolutionary ladder could then take over, leading in steps from these early forms to the vertebrates, to the mammals and to man.

Note that similar sequences characterize the scientific methodology in almost any field. First comes
the phenomenology, then taxonomy, then dynamics and finally structure. Taking Chemistry as one example, we have first Priestley (1733-1804) and Lavoisier (1743-1794) uncovering the first basic reactions and opening up a phenomenology, then John Dalton (1766-1844) launching a modern

version of Democritus' atoms, the concept of a chemical element, whose mass is conserved in any chemical reaction. In this preliminary cycle, a little phenomenology already gives rise to a very rough structural step. A second cycle then begins, with half a century of phenomenology at that level and with a large number of new chemical elements appearing here and there, with no notion as to what to expect. next and of what is still missing -- until in 1869 the "Periodic Chart of the Chemical Elements" is proposed by Dimitri Mendeleev (1834-1907) (note that there were also alternative taxonomic suggestions, but Mendeleev's was the most faithful to the phenomenology and did not attempt to fit an {\it a priori} structural model). Mendeleev's classification was convincingly validated, when elements predicted by it were indeed found, with the correct characterixtics of valency etc.. Meanwhile, radioactivity was discovered in 1896 by Henri Becquerel (1852-1908) and before long it became clear that radioactive transitions include {\it transmutations} between different chemical elements, i.e. between different boxes in the Chart. J.J. Thomson (1856-1940) discovered the electron in 1897 and Rutherford (1871-1937) explored the inner structure of the atom (1911), discovering it to have a "solar system" construction, with all but 1:2000 of the mass concentrated in the nucleus. With J. Chadwick's (1891-1965) 1932 discovery of the neutron, the structure of atoms was unraveled and explained the Periodic Chart, sixty-four years after its postulation. .

Another such example is given by the uncovering of the structure of the electrons' orbital "shells" in the different atoms.. The phenomenological background consisted in the observation of the emission spectra of different atoms (later also absorption spectra). The data kept accumulating until, in the last quarter of the XIXth century, J.J. Balmer (1825-1898), Th. Lyman (1874-1954) and others perceived an ordering, a regularity, in the form of an empirical formula which allowed one to predict where the next line would be found, i.e. at what wavelength. Balmer's formula characterized a certain subset in the spectrum of hydrogen, which became known as the "Balmer series". Lyman found a slightly different formula, characterizing another "series", etc.. The emission lines in the spectrum of hydrogen were thus classified into series, with an ordering within the series. In 1916, Niels H.D. Bohr (1885-1962) constructed an {\it ad hoc} model which reproduced the entire system. The last act was played out in 1925, when Quantum Mechanics was discovered: E. Schr\"odinger (1887-1961) re-derived Bohr's formula from his wave equation -- and W. Pauli (1900-1958) obtained it independently from the {\it "uncertainty relations"} of W. Heisenberg (1901-1976) and using his {\it matrix mechanics}. A similar process occurred with the understanding of the structure of atomic nuclei, where J.H.D. Jensen (1907-1977) and Maria G{\"o}ppert Mayer (1906-1972) managed to "read the pattern" (the {\it "shell model"}).

I had the good fortune of partaking in a similar experience in Particle Physics in the summer of 1960. Faced with a jungle of close to a hundred different {\it hadron} species ("elementary" particles -- such as protons or neutrons -- carrying "charges" inducing the {\it "strong" (nuclear) interaction}, i.e. the force gluing together protons and neutrons in any atomic nucleus) I managed to identify and read the pattern, thus. launching the taxonomic stage. Shortly after this, I also took the first step in the structural phase, leading to the discovery of a further layer ({\it quarks}) of the "onion" of matter.

Examples of such processes can be found in many areas of science. Note that all our above examples draw their dynamical existence from the Quantum level and are thus characterized by a quantized energy spectrum. Looking. instead at the Solar System, we have Sumerian, Egyptian, etc.., and latest Greek Astronomy, then the one-thousand years' hiatus of the Middle Ages, then Tycho Brahe (1546-1801) – all of them supplying the phenomenology, Johannes Kepler (1571-1630) discovering the {\it regularities} ("Kepler's three laws"), rather than a quantized energy spectrum), Nicolaus Copernicus (Mikolaj Kopernik, 1473-1573) having already provided a preview of the structural model and finally, Isaac Newton (1642-1727) uncovering the precise dynamics, plus Albert Einstein (in 1915) making it all more precise..

\vspace{.3in}
{\bf 1.3 Evolution and the clash with Religious or Political Dogmas}

Back to Darwin and his theory, we note that a fierce battle over it lasted between the publication of {\it The Origin of the Species} and the Nineteen Thirties. First, there were the Fundamentalists -- Christian, Islamic or Jewish -- who stick literally to the Story of Creation, as related in the Bible or in the Koran. The battle was fiercest in the USA's southern states, where Christian Fundamentalism is strongest -- witness the "Monkey Trial". On the threshold of the Twenty-first Century, there are still, in the USA, several states where the law requires the schools to teach "the two theories", i.e. Evolution and "Creationism" -- the latter being a "scientific version" of the Biblical story of Creation. The simplest version of Creationism is the one in which, faced for example by the geological and other evidence for the creation of the Earth some three thousand million years ago, versus the Biblical story of Creation having occurred just five thousand and seven hundred years ago, one just assumes that the Lord indeed created the world at that time -- but {\it made it look} like something which had been created billions of years before.. This version does not clash with the scientific evidence and is the easiest for a peaceful coexistence of Fundamentalist Religion with Science.

So much for Protestant Fundamentalism. The Catholic Church, however, after its initial clash with science in the Sixteenth and Seventeenth Centuries, has meanwhile gone to the other extreme, even (justly) taking partial credit for the general advance of science, by encouraging the Order of the Jesuits to very actively partake in the scientific venture, especially in the earth and planetary sciences, in astronomy and in the biological fields. Such a position, however, was not openly expressed by any Pontiff before the Nineteen -nineties. For example, whereas as late as in 1950, Pope Pius XII issued an encyclical, with a warning against the theory of evolution, "because it is exploited by the atheists, in their effort to deny the role of God in the Creation of the Universe". contrary to this approach, we have Popes John XXIII and more so John-Paul II canceling much of this material, including the cancellation of the inquisition's verdict against Galileo Galilei. Furthermore, in a 1996 encyclical declaring that {\it further facts tend to validate the Hypothesis of Evolution, which can now be considered as a true theory}, John-Paul II completed the process of inverting the position of the Catholic Church, from a bulwark of anti-science indoctrination into an ally of scientific research, beyond any other religious establishment.

In Judaism, from the times of the Mishna, (roughly 300BC - 200AD) and more so with the impact of the great biblical commentators in the XI-th Century, there are four accepted interpretations of scripture, designated by the acronym {\it PaRDeS}, which, in the Persian of the first century AD, meant "garden" and gave the word "Paradise" to the languages of Western Europe. In the acronym, "P" stands for {\it PSHAT}, which means the "literal" meaning, i.e. a fundamentalist approach, "R" means {\it REMEZ}, an allegory, so that it implies an allegorical approach, "D" stands for {\it DRASH}, which represents "hermeneutical derivation" and "S" stands for {\SOD}, which means "secret" and represents {\it mystical revelation}.

The other relevant distinction is between two different views regarding the understanding of what constitutes a {\it miracle}. There are, on the one hand, those who believe that miracles occur without violating the Laws of Physics or Chemistry, etc, i.e. without violating the Laws of Nature. This position in Judaism generally coincides with that of the members of the Allegory ("R") or Hermeneutics ("D") schools, whereas the fundamentalist ("P") and mystic ("S") schools tend to take the second position. In their perspective, it is the fact that such a process has to violate the Laws of Nature that makes it a miracle. The "R" and "D" schools thus never clash with science, whereas the "P" and "S" do. We shall return to this topic in the sequel.

A different type of resistance to Darwinism came from the {\\it Vitalists, who believed that 'Life' and 'Living Matter' cannot be described in terms of just physics and chemistry, as there had to be "something more"} and of a different nature, to account for life, to make a {\it soul}, something immaterial. This resistance has gradually dissipated, but it will not disappear as long as there is no complete scientific description of {\it thinking matter}, i.e. of the {\it mind} and of {\it cognition}.

Yet another type of resistance came from the {\it Neo-Lamarckists,} who held on to a hypothesis according to which the evolutionary drive has to be animated by a strong {\it will,} shared by all individuals within the species, who thus generate a psychological pressure, forcing their genes to mutate. The anglo-irish author Bernard Shaw (1856-1950) was an adept of Neo-Lamarckism, around which he wove the theme of the play "Back to Methuselah". In this play, mankind mutates into a species with a 300 years life-span, after a collective realization that such a prolongation of the life span is essential to the fulfillment of humanity's role and destinies. Neo-Lamarckism is thus not an anti-evolutionary movement, it is sectarian only in the sense of sticking to one particular hypothesis at the realization level, a hypothesis which ended up being refuted by Molecular Biology. Yet a painful struggle developed in the USSR around one aspect of this hypothesis.

Trofim D. Lysenko (1898-1970), who dominated over all biological research in the USSR and believed in the {\it genetic transmission of acquired characteristics}, based his beliefs on Neo-Lamarckism, namely on the impact of the acquired mutation's advantages making it "acceptable" to the genes. Lysenko's actions represent one of the lowest points in the history of science, as he was supported by the dictator (Stalin) and suppressed (literally, in this case) any dissenting voice, through the application of death sentences or of deportation to a gulag. As a result, the bio-sciences in the USSR were in a very bad shape and have not completely recovered to date. A similar effect occurred in geophysics, where the "leadership" of Vladimir V. Belousov (1907-1980) meant that no Soviet geophysicist could assume the hypothesis of the motion of the continental plates, without a danger to his livelihood and sometimes to his life.

The Neo-Lamarckists were nevertheless defeated, once it became very clear that in no way could one include acquired characteristics in one's genetic inheritance. One famous example of such a type of inheritance consists in methodically cutting the tails of mice. No matter how many generations will undergo this treatment - it will not produce tail-less mice. The way to achieve {tail-less}ness consists in favoring the naturally shorter-tailed mice - in any natural random distribution of tail-lengths, probably Gaussian (bell-shaped) - over the rest of that distribution. Feeding them better than the rest, creating conditions in which the males and females with the shorter tails will have good opportunities to mate and reproduce - this kind of environmental selection, out of a naturally random distribution, when, repeated methodically over several generations, will definitely yield an enhancement of the shorter-tailed types.

Note that even though in the case of anti-Darwinism itself (as against resistance to a sub-hypothesis), the antagonism stems mostly from religious motives, there could be other known sources of anti-science sentiment. It is instructive to study other cases of clashes between science and some world-view. We have recently had two such examples in physics: the anti-Relativity movements on the one hand and the negation of Quantum Mechanics on the other. In Nazi Germany, the regime was antagonistic to Relativity because Einstein was Jewish and therefore anything he produced had to belong to "Jewish Science" and thus had to be wrong. Both in physics and in mathematics, there were good scientists who adhered to this position. The German mathematicians Ludwig Bieberbach (1886-1982) and Oswald Teichm{\"u}ller published articles explaining why "Jewish Mathematics" was so degrading and "Aryan Mathematics" so exhilarating. Nobel laureates Johannes Stark (1874-1957) and Philipp Lenard (1862-1947) similarly wrote about "Jewish Physics" and "German Physics". Both of these were experimentalists and had an intense dislike for Relativity, which they were thus happily throwing away with its Jewish discoverer. Others, however, who wanted to keep the theory, faced a problem, until a "practical" solution was found, by "discovering the true discoverer of Relativity". This, the German establishment claimed, was not Einstein, it was Fritz Hasenoehrl, an Austrian ("pure" Aryan) theorist, a student of Boltzmann and the teacher of Schroedinger, who was killed in the First World War. Hasenoehrl could thus not answer questions and would not deny the Nazi story, which made him the inventor of both the Special and the General theories of Relativity. One could now accept and apply either theory without fear…

In the USSR, both Relativity and Quantum Mechanics were, at some stage, declared to represent {\it elitist bourgeois thinking}, whose aim was "to hide the physical truth from the working classes", a claim which was revived by the student leaders in the student rebellion of 1968.in Italy and Germany.
The non-deterministic nature of Quantum Mechanics appeared, in the eyes of the political leadership of the USSR in the thirties and forties, to clash with {\it Dialectical Materialism}, a doctrine considered as the foundation of Marxism-Leninism, which held the position of a state-religion under Stalin. The latter even enjoyed playing the role of philosophical leader of this movement. Particle physicists learned to protect themselves – e.g. from accusations of wasting the workers' means on abstract questions -- by quoting V.I. Lenin's remark (in {\it Materialism and

Empirico-criticism}), reacting to J.J. Thomson's discovery of the electron, "even an electron is as inexhaustible as an atom". This was proof enough that the research was along a path recommended by the highest spiritual authority of this "religion" .*${}^{*}{\begin {\footnote{On the other hand, the "doctrine of inexhaustibility" – namely that the number of "layers" in the "onion of matter" is infinite -- became part of the communist dogma.}

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{\bf 1.4 The micro-structure: Genetics and Molecular Biology}
What was really missing in Darwin's presentation was an understanding of the "machinery" involved, namely -- where and how are the organism's composition and structure determined, how is this information stored, how is it transmitted over the generations, when and where do the mutations occur? The first set of answers was provided by {\it genetics}, a science launched by an Austrian priest, Gregor Johann Mendel (1882-1884) who in 1856, in his monastery at Brunn (now Brno in the Czech Republic) started a methodical set of plant-breeding experiments in which he studied the results of cross-breeding in pea-plants, tracing seven characters (stem length, flower position, pod color, etc.) over several generations (noting, for instance that in the second generation the numerical ratio is simply 3:1, etc.). The outcome is known as Mendel's two laws, namely (1) that each character is determined by two factors, one from each parent, only one of which will finally be present in the egg or sperm-cell of the resulting organism – and (2) that this selection of one out of the two contributed factors is not correlated for different characters. Also – the characters do not blend on cross-breeding, they retain their original identity (an important fact for evolution). Mendel published his results in 1866, but Darwin never heard of Mendel and his work (though Mendel did read "The Origin of Species"). Mendel continued (for two more years) to experiment on other plants – until in 1868 he was promoted, becoming the monastery's abbot.. His work went mostly unnoticed
till 1900, when it was "rediscovered" and its importance first realized.

The remaining questions were answered by Molecular Biology. This scientific discipline was launched in the XXth century by a distinguished physicist, Erwin Schroedinger (1887-1961) Schroedinger, one of the founders of Quantum Mechanics in 1925 with his wave equation, became disgusted when it gradually became clear that the only interpretation of his wave function $\Psi(x)$, that was withstanding all tests was Max Born's probabilistic interpretation (namely that this complex function's squared absolute value represents the probability of the electron being at x – or more generally, being in that state). Clearly, one thus had to abandon determinism and even worse than that – the probabilistic aspect here is not a matter of our not being properly informed – it is {\it the reality itself which is probabilistic}. In the sequel, we shall return to this aspect – which disgusted Einstein, L. de Broglie and Schroedinger, three of the most important pioneers of the theory. What is relevant to our story is that in 1944, the disgusted Schroedinger (who, as an active anti-Nazi had to flee Austria in 1938 and spent the years 1939-1956 in Dublin) published a book {\it "What is Life"} with visionary insights such as the existence of a "code" (in modern terms, it is really a "program"),

{\it "with the molecular picture of the gene, it is no longer inconceivable that the miniature code should precisely correspond with a highly complicated and specified plan of development".}

Many physicists, chemists and biologists were inspired to enter this new field and search for that "code". Prominent among them were Leo Szilard (1898-1964), Max Delbrueck (1906-1981), Francis Crick (b. 1916) and many others in the younger generation. Leo Szilard was one of the most imaginative researchers of the generation – the only physicist who predicted nuclear fission and the possibility of a sustained neutron chain reaction, right after Rutherford had proclaimed (1934) that whoever thought that one could ever retrieve the energy from the nucleus was "pipe-dreaming".. Szilard did not publish his prediction; instead, he applied for a patent, and assigned it to the British Admiralty (as a Hungarian Jew, he was a refugee in England at the time, leaving for the USA in 1938). During the war, Szilard was the main initiator of the nuclear weapons program (in the USA), viewing it as an essential deterrent, in the fear that Nazi Germany might get there first. After the dropping of the bombs on Japan, Szilard (who had opposed its use against Japan) left physics and moved to biology, displaying much competence as an experimentalist in the new field and influencing a new generation of biologists.

In that search for the genetic 'code', an important step, due to Linus Pauling (b. 1901), consisted in the use of X-ray diffraction and electron-diffraction techniques to unravel the structure of some biological molecules. Pauling also identified the first case of a helical structure. Meanwhile, in 1951 in Cambridge (UK), Francis Crick, an English graduate student in physics, who had been inspired by Schroedinger's book, collaborating with Jim Watson, an American graduate student in Biology, used X-ray diffraction to study the structure of DNA, the genetic material's molecule which had been identified and studied chemically and physically by P. A. Levene, E. Chargaff, A. Todd and L. Pauling. More X-ray diffraction work by Maurice Wilkins and Rosalind Russell at Cambridge itself helped in achieving the two results, namely mapping of the spatial structure and organization of the DNA molecule and deciphering the genetic code, both tasks being completed in 1953.

The cybernetic program, namely the DNA molecule – and the related other nucleic acid, the RNA "messenger" molecule -- are built out of 'nucleotides', compounds {\it organized in four "bases" (adenine, cytosine, guanine and thymine – or A, C, G, T)} which play the role of the {\it dot} and {\it dash} in the Morse (telegraphic) code. In telegrams, the conveyed information consists of sentences in the English language (for example). An English sentence represents an ordered sequence of words, separated by either an empty interval or any one out of six punctuation symbols. Words (and in English, there are several thousand different ones) consist in arrays of letters, selected out of the 26 letters of the English alphabet Each of these 26 letters is uniquely represented by one grouping of from one to four (dot or dash) symbols – and to each such grouping of up to four dashes and/or dots, there is a unique corresponding letter in the English alphabet.

In the case of the genetic code, we might, for instance, consider the building of proteins (making up the enzymes in the chemistry of the human body) from amino acids. There are 20 different amino acids, with up to 200 such amino-acid molecules entering into the make up of any one of the proteins (of which there are hundreds of types). The 200 amino acids for any one protein represent a uniquely ordered sequence, involving most or all of the 20 amino acids. The proteins are thus the analogs of words, the 20 amino acids are the analogs of the 26 letters in English. This is then the conveyed information, the parallel to the English sentences conveyed by the Morse code.

In the genetic code, the 20 amino acids ("letters") are represented (or enciphered) as groupings of three nucleotide bases, out of the available four (A, C, G, T). Groupings like [AAC], [ACG], [CGT], etc., code for the amino-acids, just as English "a" is written in Morse as [. -], "b" as [- . . .], "l" as [. - . .], "m" as [- -], etc. In this manner, the instructions for the construction of any one of the proteins are set up precisely in the genetic code. The chemistry and physics are such as to make any such set of three bases pick up its unique correspondent, among the 20 amino acids, in the construction processes taking place in the making of a living being (the DNA itself also has to be recopied for every new cell in the animal)... .

We now return to Darwinism, formulated as it was, before the discovery of the genetic machinery and its workings. The Mendelians criticized Darwin, claiming that the true selection process must be taking place in the genes, rather than at the level of the organism, as claimed in Darwin's original thesis. We now know that {\it selection} occurs both microscopically, in the genes -- where {\it mutations occur as errors in the process of copying the DNA molecule} -- and macroscopically, in the organisms' populations, i.e. according to Darwin's original thesis. The latter process is mostly at work in the case of the {\it extinction of an individual species}, as a result of a change in its environment – the most common such change consisting in the emergence of either a new predator species or a new species with some advantage in the competition for the same source of food. The recent discovery that at various stages {\it homo sapiens} coexisted with some 15 other hominids [ ] appears to be such an example..

This amended version, in which evolution occurs at both levels, that of the {\it gene} - in the making of mutations, i.e. therefore essentially in all {\it good mutation} cases – and in that of the {\it organisms} in the opposite case, namely in {\it passive} bad mutations, i.e. in the encounter with new environmental conditions for which the genetic set up is less fit, this modern version, known as {\it Neo-Darwinism}, is the one adopted by the professional consensus since the nineteen-sixties.

{\bf 1.5 Modern Variants: Punctuation, Catastrophes}

Meanwhile, the understanding of the various secondary processes has grown and makes it possible to identify several principal variants, within the precise mechanism of randomization and selection. One such effect is known as {\it punctuated evolution}, discovered in the nineteen sixties by Gould and Eldredge. The idea is that {\it evolution works much faster when the mutation occurs in an isolated and relatively small population}.

An example of a highly successful {\it punctuated} transition is the rebirth of Hebrew (now the language spoken by six million Israelis, including one million Arabs, for whom it is the second language) as a spoken language. This rebirth was achieved by Eliezer Ben-Yehuda, in the beginning of the XXth century. On the other hand, the attempted revival of Irish-Gaelic in Ireland, at roughly the same period, was a failure. In the Palestine of 1900 (then a province of the Ottoman Empire), each Jewish community was using its own version of the language of their recent or former countries of exile - Ladino (XVth century Castilian) by the Sefaradim, Yidish (XIth century German) by the Ashkenazim, Judeo-Arabic for the Syrian and Iraqi Jews, etc. But the entire Jewish population of "Eretz-Israel", the Land of Israel, Biblical Palestine, numbered around 150.000 souls in 1900 (with some 200.000 Palestinian Arabs). It was thus relatively easy to convince a majority within these 150,000 Jews to adopt Hebrew. For example, the number of Jewish elementary schools was small, which made it much easier to convince a majority of headmasters, etc. Once this was achieved for this small group, every new immigrant (and the total number of immigrants since that time is around three million, with almost no one speaking Hebrew prior to their arrival) has been faced upon arrival with the fact that to communicate within the Jewish community he or she had to study Hebrew. In Ireland, on the other hand, there were three million English-speaking Irish, yet the Irish nationalists were less successful in their attempt to spread the use of Gaelic-Irish. To be entirely fair, we should add another factor, namely that there had always been a need for an inter-community language and that Hebrew had been naturally in use in this role (with a very limited vocabulary), as all Jewish males, at least, had attended a {\v h}eder (elementary school teaching reading and the Bible) and most had also attended a Yeshiva (talmudic school) and were thus familiar with Biblical Hebrew and Talmudic Aramaic - whereas knowledge of Ladino, Yidish or Judeo-Arabic was confined to the relevant sector of the population.

Yet another variant, which has been adopted as an alternative process fitting some specific boundary conditions, is {\it "catastrophic"} evolution. The idea is due to my physicist-friend, the late Luis Walter Alvarez (1911-1988, Nobel prize 1968) of the University of California at Berkeley and to his son Walter. Progress in Paleontology and Geology had revealed a new and weird mystery. At several of the transition layers between two geological eras, one discovers in the paleontological record an extremely bizarre feature, namely the vanishing (within a few million years) of several hundreds of thousand species. This appears to be very different from the alternative we mentioned, namely the extinction of an individual species – in which case it is generally possible to reconstruct the new environmental conditions which caused this isolated demise of a species. In the catastrophic cases, taking, for example the border between the Secondary and Tertiary, i.e. the end of the Cretaceous, about 65 million years ago, one discovers a process in which, within one million years, no less than {\it a million species} (including the dinosaurs, in this case) disappear. Luis and Walter Alvarez discovered a layer of Iridium, present at all sites representing that geological transition That iridium layer appears to indicate the action of a comet, since this metallic element is very rare on Earth, whereas it is found in relative concentrations in the comets. We have witnessed, in 1994, comet " Shoemaker-Levi 9" crashing onto planet Jupiter. That iridium layer might well be the result of a similar event on earth, 65 million years ago. The recurrence might possibly indicate that our Sun might be passing through a region full of debris and candidate comets, once every 65 million years.. One large comet might then have fallen on earth, triggering a blackening of the atmosphere, hiding the Sun.. Should this have lasted over several years, it might well have finished off the dinosaurs - and given a boost to the smallish mammals, who could feed on the dying dinosaurs. Note that all of this resembles the "Nuclear Winter" model, studied in 1980-1990, within the context of nuclear deterrence.

Similar disappearances of a very large number of species appear to have taken place 250,000, 460.000 and 650.000 years ago.. It has been suggested that the Sun is part of a binary system, i.e. that it has a partner, whose return every 190 million years causes all of this unrest...

This kind of occurrence can be taken as a model for a new evolutionary mechanism, under the title, {\it survival of the luckiest}, instead of the {\it fittest}. Note that both the term {\it Evolution} and the phrase {\it survival of the fittest} were coined by the English philosopher Herbert Spenser (1820-1903). As to our present innovation -- "survival of the luckiest" -- it turns out that it has already been "studied" in the Science-Fiction literature. In his novel "Ringworld", author Larry Niven describes a world in which humans are not free to reproduce. Every year, there is a lottery, and the lucky winners get permission to have one child. Clearly, this is "breeding for luck" (which would require a "tongue in cheek" formulation)...Returning to the role of Spencer, we note that he was writing and publishing material about "evolution", {\it progress} etc., in a very general way, before Darwin's publication of "The Origin of Species". After the publication of "The Origin of Species", Spencer adopted Darwin's ideas and formulation. Moreover, Spencer's books were well received in Europe and helped spread Darwin's evolutionary message.

Another philosopher of the XIXth Century who was influenced by Darwin is Friedrich Nietzsche (1844-1900), whose thesis played an important and sometimes even terrible role in the XXth Century. We shall deal with his approach in Part II of this book

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{\bf 1.6 The Structure of an Evolutionary Process}

We now analyze the elements of evolutionary processes, as conceived in Neo-Darwinism. The necessary arena is a structure carrying a {\it cybernetic program} -- the DNA molecule with its encoded message of instructions (here the genetic code, as explained in section 1.4) providing the cybernetic control over the biological construction of the organism.

The evolutionary process consists in an interplay between two mechanisms: (a) random mutations occurring in the encoded information in the cybernetic program -- and (b) "natural" selection, occurring at either the "program" level -- or at that of the organism -- plus some conditions guaranteeing continuity, i.e. that this be an open-ended sequence, never reaching equilibrium and never stopping.

{\bf (a) Mutations of the controlling elements}\\.
It is a well-known fact that the structure and properties of any {\it living} system, whether it belong to the animal or vegetal kingdom, are determined by information which is coded into the creature's DNA molecules. We saw in section 1.4 how four nucleotide "bases" play in the genetic code the role of the 'dash' and 'dot' basic elements in Morse's telegraphic transmission 'code'. Note that the genes carried by the creature's chromosomes do contain in addition "neutral" regions, but without our going into further details, the DNA molecule, as stretched out along the gene, can be described as the 'book of instructions' according to which the creature was designed. {\it The organism continuously activates a mechanism which makes new copies of the creature's DNA molecule,} a procedure involving the RNA molecule, in the dissemination machinery. The copying procedure itself suffers from errors, with some {'words'} of the coded 'message' thereby getting lost from time to time. In most cases, the damage is minimal, e.g. some property might loose its sharpness. In some cases, however, a real modification in the constitution and functioning of the organism will have occurred, perhaps causing the invalidation of a limb, for instance, or, on the contrary, the acquisition of additional redundancy, generally a useful feature.

The mechanism responsible for the emergence of mutations, in the process of making copies of the DNA , is well understood today. One can even evaluate the rate at which new 'stable' mutations will occur - or have occurred, in bio-historical studies. "Stable" implies being incorporated in the new gene. This can be a mutation in the molecule, positive or neutral, which becomes 'established' within the gene. The methodology has been further developed, enabling one, for instance, to evaluate when in the past genetic history have two given (nowadays very different) genes first separated, i.e. when did the distinguishing mutation occur in the DNA of their common ancestor. For such related mutations, one measures the {\it genetic distance}, i.e. the number of mutations necessary in order to get from one descendant gene to the other. One may thus quantify biological (or paleontological) "genealogies". Our Darwinian relationship with the great apes - or with the chimpanzee - has thus acquired a quantitative representation, including both "distance" (i.e. the number of separating mutations) and "time" - evaluating when did the separation start. In recent years, the method has also been applied to the AIDS virus, to evaluate the distance between it and a related virus which lives in apes. This distance was found to be rather short, the mutational separation having apparently occurred within the last thirty years!.

Yet another study of great interest has resulted in bringing together three powerful and very different methodologies, namely {\it genetics} in DNA-dating and genealogical ancestor tracing, {\it archeology-anthropology} and {\it linguistics}. This study used DNA samples from several thousand persons, covering all existing races of man, but concentrating exclusively on the DNA from mitochondria, i.e. a type of DNA present only in women. One general result has consisted in the sketching of the "tree" of human races, but the more spectacular finding was the discovery of "Eve", one woman who lived some 200.000 years ago, apparently in North Africa, and who is present in the ancestry of every person presently alive. Note that this does not imply the existence of an "Adam and Eve" couple from which we are all descended. The original group may have counted several thousand souls, but 'Eve' had the good luck of having relatively many descendants, and these must have married into every other family, so that when climbing back into the ancestry of any presently living human, one is bound to encounter one of Eve's descendants. It is gratifying to know that these findings are supported by the two other available methods for such studies: archeology-anthropology and linguistics. Prehistoric archeology studies human settlements, human skulls and bones, etc Most prehistoric archeologists do also believe that {\it homo sapiens} left Africa a quarter of a million years ago and spread out onto all continents, replacing populations of previous human stock (Neanderthal, for instance). As to language, Joseph Greenberg's comparative method (building up for any language a certain list of a few thousand essential words and then comparing with the lists corresponding to other languages, identifying the overlap), aside from leading to the reconstruction of parent languages (such as Indo-European, Nostatic, etc.) also enables one to identify the geographical location of that linguistic group. It turns out that this approach indeed also confirms the findings based on mitochondrial DNA.

One more comment about the AIDS virus. It possesses, apparently, an enhanced mutational mechanism, making it possible for it to mutate {\it on line}! This is, as a matter of fact the key to its tactics and the secret of its killing rate. Whenever a virus shows up within a living person, the patient's immunological system reacts by creating antibodies, whose role is to stick to the virus, thereby obstructing its further entry into vital areas. Yet this does not work in the case of the AIDS virus. That virus exploits its enhanced mutational capacity and undergoes "on-the-spot" mutation. The immunological system of the patient is taken in by the trick: it notes the penetration and the presence of a "new virus" – and sets on producing antibodies for the "new" virus.. The virus, on the other hand, mutates again "on line" and the body's immune system works hard, creating new antibodies all the time – until it has exhausted itself and cannot react normally to the next versions of the supermutating virus, which has thus defeated the patient's immunological systems.

Let us now return to our main theme and study the role of {\it randomized} mechanisms in evolutionary processes. It will be useful to compare this randomness with other cases of randomized action in Physics. In the XIXth Century, probabilistic considerations first appeared via the Kinetic Theory of Gases, and later in the treatment of radiation. Finally, probabilistic notions entered as the basic algorithm of Statistical Mechanics, seen as an axiomatic foundation for the laws of Thermodynamics. The key treatment was developed by James Clark Maxwell (1831-1879), Ludwig Boltzmann (1844-1906) and Willard Gibbs (1839 – 1903), with Albert Einstein completing the construction (this was the fifth 'super' article in his 'miraculous' 1905 production).

In those situations, the reliance on probabilistic and statistical modes was due to facts such as the value of the Avogadro-Loschmid number (of the order of 10^{24}), which made it impossible to list and record the positions and velocities of all particles in a macroscopic problem, thus forcing us to adopt statistical notions. Note that the advances in computer hardware might yet make it possible, these days, indeed to label the participating 10^{24} molecules – except that we have meanwhile also been forced to change the scenery – from classical to quantum (1925) – and there is no point anymore in classically following molecule by molecule, when the basic dynamics are quantum dynamics anyhow. Note that {\it the probabilistic nature of quantum mechanics is not due to statistical considerations}, as ("hidden variables" theories have been shown to breed problems and require action-at-a-distance for these variables).

The probabilistic algorithms of Quantum Mechanics emerge from the very nature of the theory and represent a second source for probabilistic considerations. A new (third) source of non-deterministic behavior and probabilistic considerations has recently appeared on the physics scene: this is the "{\it chaos}" mode, in which {\it tiny modifications in the initial conditions may bring about totally different macroscopic results}. One might label evolutionary processes as a fourth source of probabilistic considerations..

The probabilistic element in the mutations of DNA strands, however, is not a total lottery, it is more like the occurrence of spelling errors in a telegram. Sometime the error does not interfere with the message. In other cases it might happen that a word has been replaced by another, but it is still obvious that the new word is not part of the original message. In other cases, however, the new word fits well in the sentence, even though it reverses the original meaning. In any case, we are not dealing only with pure chance, but rather with chance modifications of an original text, adding up cumulatively. The opponents of Darwinism used to ask "Is it plausible that by sheer chance, 10^{28} atoms happened to form a human brain?" This is not how chance enters in Neo-Darwinism. It is a gradual process, with billions of billions of steps, each consisting of the mutation of one "letter" at a time. This is also why there is no paradoxical issue about the {\it time necessary for evolution to produce humanity} as compared with the presently accepted value of the age of the universe.

{\bf (b) Natural Selection}.\\
Now for "natural selection" – let us take a few examples. A simple negative selection might be caused by structural considerations within the gene itself: Whatever the mechanism, if the modified gene is unstable, it will not be included in the final gene material which goes with the sperms and serves as blueprint for the fabrication of the DNA of the offspring. Sometime, it will be the other way around: the mutated gene is very stable and even adds stability to the relevant chromosome. That mutated DNA will survive until it will be incorporated in the DNA transmitted to the offspring. The offspring, will thus represent a new organism. This is where the original Darwinian selection will take place, at the organism's level a selection occurring macroscopically, as in Darwin's original thesis. In any case, the sequence opens with a mutation in the genes and will end likewise; the main arena where natural selection occurs is the gene itself. The English biologist Richard Dawkins has appropriately given one of his books the title "The Selfish Gene".

{\it (c) Negative Selection or Extinction}. \\
"Dead as a dodo" is another phrase contributed to the English language by biological evolutionary theory. The extinction of this large flightless bird ({\it Raphus cucullatus}) on the island of Mauritius since the XVII-th Century somehow managed to impress the public and make it realize that what happened to all those prehistorical animals could still happen in our days. The workings of evolution in these situations correspond to what we have designated as a "type E process: instead of that animal's DNA mutating and evolving, the "mutating" element occurs in the selective constraints generated by the environmental conditions. The dodo must have fitted well with the previous conditions on Mauritius, but the island changed and the dodo did not fit any more. Of course, in most such cases in modern times, the change in the environment is a result of {\it human regional development initiatives}, and it has taken many dodo-like extinctions for the public to realize it is responsible for the disappearance of all these species and for governments to organize a machinery for the ecological monitoring, surveillance and control.

{\bf 1.7 The Physical Characteristics of an Evolutionary Process.}

{\bf (a) Dissipative Systems}
Let us try an elementary model. We pick up a simple box and fill it up with nuts of two kinds, ordinary (small) nuts and (large) Brazil nuts. We now {\it shake} the box, thus contributing both a supply of energy – and a source of randomized kinematics. After some time, of the order of tens of minutes (or less than an hour), opening the box, we discover {\it order}. All small nuts make up the bottom layer, with the Brazil nuts sitting on top of them. The ordering mechanism is clear: every time several large nuts form a horizonal layer, our shaking will bring some small nuts sitting on top – but they are bound to fall down, to the lower layer, because the large nuts leave large "loop-holes" between their idealized circles. The opposite set up never occurs: the loop-holes between small nuts are too small for the large ones to fall through. This example contains some of the key elements of a dissipative system. We observe the need for an ongoing

supply of random motion – here the shaking energy. Also, we make partial use of gravity, to have all nuts trying to fall through the gaps between other nuts. The system is clearly {\it dissipative}. However, this was only a one-step process, one "atom" of evolution. To have an ever-evolving system, we would need either an infinite ongoing supply of nuts too – which would just perpetuate the elementary process – or some way of having nuts of a new size appear some time after the first pair have reached equilibrium – and thus start a new sequence.

And yet this is not the full story. The energy consumption here is used solely for the creation of order, not for its preservation. In crystal growth, gravitational energy is consumed, as in the present example - but once order has been created, it is preserved by the presence of a thermodynamical equilibrium. In a cyclone, in the human body as an ordered system, or in the Benard instability, energy is needed in the process of preserving the order, as these systems are far from thermodynamical equilibrium.

{\bf (b) Teleonomy}.
This simplified example thus contains most elements that we considered as characterizing the dissipative mode: a supply of randomization, an energy feeding mechanism. We also observe {\it self-ordering} and {\it teleonomy}, i.e. the impression of an {\it aim}, a machine set to produce an ordered system. Here, we could describe our set-up as "a machine to separate nuts according to their size".
Note that such systems do exist in nature, for instance in geological layers which were once at the bottom of the sea and contain stones of various sizes. The action of currents or sea-waves ends up organizing the layers by the sizes of the stones. A process of the same class can be observed in the growing of salt crystals, using a salt-solvent in a saturated solution Most processes involving the human body are naturally dissipative, as it replaces all its atoms within a three-year cycle. A continuous feed of food plus oxygen for breathing is essential for these experiments. Note that even though all atoms in the human body are relatively new "recruits", the body itself relies on its memory system and regards itself as the same person as the one who carried this name four years earlier. The same is true of a hurricane or typhoon: the atoms of the wind and of the dust are replaced all the time, but the hurricane exists as an entity all along its path.

{\bf (c) Decreasing Entropy, Self-Organisation}
According to the "Second Law" of Thermodynamics, the entropy within a closed system can only grow. If we are shown two pictures of the molecules of a gas within a pump's cylinder, one with all the molecules concentrated in one corner of the cylinder, the other with the molecules spread out into the entire volume – we can be certain that the one in which the molecules are concentrated in one corner must have been taken first. Once the piston was removed as a barrier – the molecules spread everywhere. The opposite history would never happen, i.e. the probability of all the molecules suddenly breaking their velocities and moving together to one corner of the cylinder – this probability is nil. And yet we also know that evolutionary processes do create {\it order}, including systems such as the human brain! A detailed analysis shows that the lowering of the entropy function (representing {\it disorder}) is accompanied by a larger entropy increase in the environment. A city, for instance, is a dissipative system; it generates order – at the price of a larger increase of entropy in the environment: sewage, air pollution, etc.. Note that {\it order}, as a concept, is different from {\it symmetry}. Thermodynamical equilibrium – i.e. maximal disorder – is a {\it symmetric} system, as there are molecules going in all directions; {\it order}, on the other hand (such as the emergence of a magnetized system, when cooling a paramagnetic material) entails a breaking of the symmetry and a lowering of the entropy.

{\bf (d) Nonlinear Processes}
The last two decades have witnessed important advances in the physics of nonlinear processes. {\it Chaos}, the name given to the physics of these processes, deals with systems (meteorology being a good example) in which a tiny modification in the initial conditions results in completely different macroscopic processes. A game of billiard may serve as an example: Hitting the first ball with a surplus angle α, i.e. "A+\alpha$, brings about that ball hitting the next one at an angle "B+2\alpha$, which will make that one hit the next at an angle $C+3\alpha$, etc.. with, say E ending up in the direction $E+5\alpha$ instead of "E" and thus completely missing the basket. Examples

of this kind are common in Meteorology, where one cites the case of the amplification of the flight of a butterfly in Brazil causing a serious change in the climate in Western Europe.

Ever since the advent of Quantum Mechanics (1925) it has gradually become clear that probabilistic features in that context originate in intrinsic sources of indeterminacy. The laws of nature at that microscopic level are generally probabilistic and non-deterministic. We have listed this source of indeterminacy as the "purest", especially after the Aspect experiments (1985), which showed that the Quantum Indeterminacy is real, not just a matter of our ignorance, or of hidden variables imposing a statistical description The indeterminacy induced by {\it chaos}, on the other hand, emerges from a limitation on our precision (i.e. it involves {\it our knowledge, not {\it reality}) - yet it achieves a true indeterminacy in macroscopic phenomena. The great mathematician and astronomer, Pierre-Simon, Marquis de Laplace (1749-1827), used to claim that if one were to be given the position and velocities of all particles in the universe, one would thereby be able to reconstruct the entire Past and to calculate and predict the complete future.

The {\it chaotic} regime marks the end of such deterministic considerations. The Belgian physicist and chemist, Ilya Prigogine, a pioneer of the study of chaos and dissipative processes, has given his most recent book the title "The End of Certainty".

Note that the same domain of "chaotic" physics displays, in addition, {\it pseudo-deterministic} features. As against the strong dependence on initial conditions, dissipative processes also tend to generate {\it "strange attractors"} in phase space. In other words, the system tends to select a path in phase space and run over it again and again. Having e.g. a million players participating in our billiard game would display these special phase space features. Following that phase space evolution, one encounters universal features of cyclic repetition, shorter cycles, etc.. These are processes of {\it self-organisation}.

These features of self-organization generate {\it order}. Examples include the spiral structures appearing in a bath-tub, with the outgoing flow of water, upon the emptying of the tub. Another example consists in the {\it Benard instability}. One fills a test-tube with a certain liquid compound. One heats the bottom of the test-tube continuously, and the liquid in that test-tube changes into an orderly sequence of colored layers, which survive as long as we supply heat . Yet another example, in which the liquid is a mix of two organic liquids, is provided by the Belyoussev-Jabotinsky reaction. The liquid displays two phases. In one we observe spherical waves originating in the center. In the second phase, one observes a flow of wheel-like structures, rolling in rows. It has been shown that the human heart behaves like the Belyoussev-Jabotinsky reaction, with the normal activity of the heart corresponding to the first phase of the B-J reaction, whereas the occurrence of the second phase may imply the death of that heart's owner…These self-organisation processes are so impressive, as they takeover and dominate, that there are biologists who contemplate a return to determinism – and perhaps even to non-Copernican approaches. In the study of the beginnings of life, one generally assumes that an important role is played by several organic molecules which are produced in astrophysical processes, processes which have indeed been observed in the interstellar milieu and could lead almost directly to self-reproducing molecules. This stage has indeed been reproduced in experiments in which one tries to recreate conditions (e.g. atmospheric) resembling those that existed on Earth one-and –a-half to three billion years ago. The American biologist Stuart Kauffman, of the Santa Fe' Institute, in his recent book "At Home in the Universe" reexamines the laws of Self-Organization and of Complexity and shows them as driving the evolutionary 'march', almost deterministically. Moreover, with evolution thus "guaranteed" as the end-product, Kauffman is led in his enthusiasm to statements which represent a challenge to the Copernican revolution. With this approach, it is not surprising that the title of his recent book is "At Home in the Universe." The idea is that rather than regarding our presence in the universe as that of freaks, admitted into reality as a result of a series of improbable accidents – the {\it inevitability}of some of these accidents is now taken to imply just the opposite – not only do we {\it belong} in this universe, on the contrary, we are its {\it selected} (or {\it 'chosen'}) inhabitants, its {\it raison d'etre}, the end-product because of whom it exists}. Clearly, the distance between this

approach and that of the first chapter of Genesis is null. Copernicus, on the other hand, taught us that the earth is not at the center of our solar system, with modern astronomy then telling us that we are situated on a side branch of one of between
ten to a hundred billion galaxies making up the observable universe. And yet we now encounter a teleological argument placing us back somewhere at the teleological center of the universe.. Note that in the eyes of this author, the evidence for such a return to centrality is infinitely less convincing than the arguments in favor of the fuly generalized Copernican view. .

{\bf 1.8 Teleonomy or Teleology – the Interaction with Religion}

The evolutionary process, almost by definition, leads from a less orderly system to one with added order. As a result, the evolutionary process propagates an impression of order and organisation, of an open future, of an unfolding program. Two terms have been coined to represent the essence of two interpretations, one purely scientific and the other involving religion. {\it Teleology} means evolving {\it for the fulfillment of a purpose}, whereas {\it teleonomy} – which we prefer – means "evolving in a manner which creates {\it the illusion of a purpose}." Clearly, religious scientists will prefer "teleology" and atheists or non-religious (myself included) will use "teleonomy" As a matter of fact, in biological evolution, there are two scales of teleonomic effects, which we can describe as {\it tactical} and {\it strategic}. At the level of the organism, one can describe the evolutionary end-product as a "machine", e.g. a machine which feeds on oxygen and carbon compounds – and produces printed articles or books (this could describe my own role in the present). Strategically, one would raise one's eyes and visualize the entire sequence, from mono-cellular beings to man; the teleonomy would then apply to the entire sequence and might be described as "From bacteria to humans – one super-program". If that were taken as teleology, it should perhaps be followed by a prayer -- thanking the creator for having developed such a program...

Religions can be divided according to their position with respect to Science. Some religions have accepted the role of science as aiming at a {\it complete} description of the physical world. In these religions, {\it the Creator operates through science}. Even when he/she wishes to display a miracle, this miracle has to be performed within the laws of physics, chemistry and biology. Such an approach is guaranteed to avoid any clash between science and religion. In section 1.3, we reviewed the changes in the Catholic Church's positions, since that clash with Galileo and cited Pope John-Paul II's withdrawal of previous objections both to physics and to biology and his formal recognition of Darwinism. We also mentioned the impact of the Order of the Jesuits' involvement in scientific research. Our story will soon provide an edifying example. We also refer the reader to section 1.3 for the analysis of accepted positions in Judaism

We have reviewed the more than negative attitude of the Christian, Muslim and Jewish fundamentalist movements. On the other hand, because of teleonomy being reinterpretable as teleology, there have been highly positive approaches by two Jesuit biologists, Pierre Teilhard de Chardin (1881-1955) and Pierre Lecomte du Nouy (1883-1947). The latter developed a new approach to the issue of whether or not there are godly interventions via non-scientific channels. Lecomte du Nouy suggested a clever way in which the extraneous intervention – though realized outside of the rule of science, nevertheless utilizes an unobjectionable route. His idea was to assume that godly intervention is restricted to {\it fixing the result of an otherwise randomized situation – or of the throwing of the dice}. This was at a time when it looked as if there had not been enough time for the whole of evolution to unfold. It was all a matter of probabilities – i.e. too low probabilities for some transformations, through which the historical sequence had to pass. Lecomte du Nouy suggested that the creator's intervention is limited to fixing the outcome of a step – for which the theory gives us an expected probability – with the intervention consisting in having selected a low probability result – otherwise leaving everything as is. Effectively, this was a realization of "Maxwell's Demon".

Meanwhile, on the Jewish side, Rabbi Abraham Isaac HaCohen Cook (1865-1935), Ashkenazi chief rabbi of Palestine in the Twenties and early Thirties, was adopting a different view. Belonging by his training to the school of thought which regards science as a mathematical description of God's doings, he sang the glories of evolution, this being the mechanism used by the Creator in the continuation of his drive, completing the creation of life. In his book "Orot (Lights)", in a chapter with the title "The elevation of the world", he writes, "Evolution, which is following a rising track, is providing the optimist elements in the world – for how can one despair, when one observes a universal evolving and rising. When one penetrates the inner core of Evolution and Transcendence, one discovers the acts of

God illuminated in a particular absolute clarity."

Teilhard de Chardin, the other Jesuit biologist, presents a position similar to that of Rabbi Cook. He also does not appeal to the supernatural, when discussing creation and its sequels. Recently (1998), Pope John-Paul II has formally adopted Evolution, stressing the positive evidence for it in his announcement.

It is interesting that one now encounters positions effectively similar to that of R. Cook or Father Teilhard de Chardin, among biologists such as Stuart Kauffman, studying self-organisation, or amongst physicists and astronomers who have adopted the {\it Anthropic Principle}. The latter are scientists who have adopted a principle which allows them to reinterpret scientifically established facts in terms of anthropocentric considerations. Such a position willy nilly returns man to a central position in the universe. This group is joined by a group of physicists, led by two of my personal friends, the late Eugene Wigner (1902-1994) and John Archibald Wheeler, recent laureate of the Wolf Prize. Both physicists developed an approach to the cause for the non-intuitive aspects of Quantum Mechanics, according to which these difficulties all stem from the incompleteness of the present formalism, in which they claim {\it the human mind} should be an essential element, as the {\it measurement recording device}. This is thus the main missing element in the existing description, in their view. Indeed, the most important non-intuitive element in QM is the {\it "collapse of the state vector"} in the act of {\it measurement}, a process in which a non-deterministic and Fully probabilistic picture is suddenly replaced by a classical deterministic one. The two above physicists consider the possibility that the formalism describing measurement ought to include the registration of the results, as performed by the human mind. This approach has not yielded interesting results to date and I believe that it will be abandoned – but meanwhile, its partisans are involved in a search for new methods of recording measurements.. I have strong doubts with respect to this entire approach, because any interaction, even with a stone, also has to count as a measurement, with no role for the human mind. In addition, the Aspect experiments showed that the quantum indeterminacy represents a truly undetermined fact. The EPR experiment with application of the Bell inequalities is a verdict according to which the chirality or spin of the "left EPR decay product" and of the "right EPR decay product" are really superpositions and do not become determined as long as the measurement has not taken place. Note that this was the specific point which Einstein found so hard to accept. In the picture he had drawn for himself, the right and left EPR products would have definite values of these quantum numbers from the very beginning, and the quantum indeterminacy would only cover the information, not the facts. However, the Aspect results vindicated the less intuitive picture. In Wigner's and Wheeler's {\it "participatory"} model, the presence of a human mind should have resolved these questions in favor of Einstein's picture – which is not what happened to date.

The {\it participatory} view in Quantum Mechanics does not have many partisans in the younger generation. In any case, biologists who are enthusiastic supporters of self-organisation as an almost-deterministic machinery, cosmologists who follow the "strong" Anthropic Principle, quantum physicists who believe that the resolution of the non-intuitive concepts arising in the act of measurement in Quantum Mechanics will come from the incorporation of the human mind into the Quantum formalism – all of these groups are driven towards a pre-Copernican view of the role of man in the universe. They regard man as the end-product for which the Universe has been created – or at least as an important participant in the act of Creation. For them, the teleonomy is a teleology, a true advance towards a purpose – really a universal program. Mostly, one does not hear religious arguments in the discussion, but the voiced positions are at least pantheistic. The opponents of Evolution in the XIXth Century used to bring up "the watchmaker" argument. Walking around, a man discovers a watch; clearly, the implication is that there is a watchmaker, since in no way would you be led to believe that this watch is self-made, i.e. that a thousand trillion trillion silver and iron atoms arranged to organize as a ticking watch! The conclusion from this argument was thus that there is a Creator. Now, however, with the advances in the understanding of dissipative processes, with the quasi-deterministic features of the self-organisation processes, and especially with the understanding that evolution is not a one-time lottery but rather a sequence of billions of small steps, with a limited range of mutability – finding that watch could perhaps still be taken as proof of the existence of a creative watchmaker – but one who chooses to work through {\it evolution}! Richard Dawkins, the British biologist we mentioned, indeed chose for one of his books the title "The Blind Watchmaker", in the spirit of our previous paragraph. Moreover, in the discussion regarding the evolutionary timetable and whether it could all have happened in three and a half billion years, he used elsewhere – in parody – the argument "Look what a marvelous thing happened to the Mississipi river – how did it manage to wind so as to pass underneath all these bridges!" Those who hold on to a religious philosophy can certainly find in evolution a support for their beliefs, but so can the atheists. It is all a function of one's beliefs. Henri Bergson (1859-1941), the

French Jewish philosopher, in his inspiring book "L'evolution creatrice", emphasizes the "open-endedness" of evolution, i.e. its non-deterministic character.

{\bf 1.9 Evolutionary Prospects}

When dealing with the open-endedness of evolution or with the quasi-determinism in self-organisatory processes, one is tempted to try and visualize the next rungs in the evolutionary ladder. The last hundred thousand years have not witnessed important biological and genetic modifications.in humans (we shall see in the coming chapters that evolution was extremely active, but at the social level). The advances in XXth Century science have, however, created serious options in this direction. Two novel paths have opened – {\it genetic engineering} and {\it computer science}.

In genetic engineering, the technique of transferring a gene or part of a gene from one living being to another is already well-developed. There are nowadays mice whose genes carry in part human DNA, and have thus become human-like in medical experimentation for certain diseases. In other cases, genes are transferred in order to generate immunity to some disease, to some parasites – or even to some environmental agent. The {\it human genome project}, a grandiose initiative in genetic medicine, should make it possible, some day, to fight genetic diseases in some populations by replacing imperfect genes.
Human genetics seem to indicate that some talents – in music or in mathematics, for instance – are carried in the genes. The possibilities appear to be infinite.

What about the other route, namely computers and {\it artificial intelligence (AI)}? The lessons from the study of the brain, together with advances in AI, tell us that each of the two "cognitive technologies" has its advantages. Up to the present, the electronic "brain" has the upper hand in the rate at which it performs direct logical computation. In 1997, for the first time , the computer {\it "Deep Blue"} managed to beat the Chess World Champion, Gary Kasparov. However, this was not the outcome of a genial strategy – it was the result of Deep Blue rapidly computing all possibilities for several steps ahead. On the other hand, man is still better than the computer in the power of association and associative connections, or also in developing shortcut strategies. In the last decade, however, a new field of study, known under the term {\it neural networks}is developing rapidly. It deals with computers resembling the human brain, in that they have the capacity of {\it learning}, and especially in learning from their own past experience.

{\bf 1.10 Propagation and generations}

In the more advanced cases of evolutionary processes one encounters {\it multiplication} and offspring, i.e. propagation over the generations. This is, of course, in the essence of biological evolution, but it also exists – in a rather elementary fashion – in astrophysical evolution, and perhaps again in Evolutionary Cosmology, a speculative area which we shall soon review. In biological evolution, one line starts with the assumption (suggested by Freeman Dyson), that life as a process is the combined result of two separate evolutionary lines: on the one hand, molecules capable, under certain environmental circumstances, of using the surrounding materials to make self-copies; and on the other hand, systems which exist as metabolic combinations, living off the environment. Examples of metabolic systems: photosynthesis, in which chlorophyl releases the oxygen in CO_{2}, or respiration, where oxygen is absorbed and energy released. The conjecture is that the two evolutionary lines were joined together by evolution at a later stage.

{\bf Chapter 2: Nucleosynthesis, Stellar and Cosmological Evolution; Cosmogony}

{\bf 2.1 Astrophysical evolution and the making of the chemical elements.}

We now turn to yet another domain in which the role of evolution has been understood since the Thirties and Forties, with the values of all parameters measured in the laboratory. This is {\it nucleosynthesis}, the system of evolutionary processes which created the present qualitative and quantitative distribution of the chemical elements in the universe. This is thus the evolutionary history of all matter, within the observable universe – and it is known as {\it nucleosynthesis}, since all these reactions belong to the field of {\it nuclear chemistry}, sometime {\it nuclear physics}. At the same time, the chemical elements appear as parts of macroscopic objects – mostly the stars – so that the story told in this chapter is also {\it the story (and evolution) of morphological astrophysics}.
We do leave out, at this stage, the study of earlier periods, both at the microscopic level (quarks, etc.) and macroscopically (the Big Bang, Inflation). We shall return to this Cosmological phase in the sequel. As a matter of fact, in the last two decades of the Twentieth Century, we have for the first time entered a new area altogether, namely Cosmogony. I shall try to include these advances in our story.

The chapter we reconstruct now starts with hydrogen, as the main chemical component making up morphologically sets of large clouds, with the latter making up the content of the extremely young Universe. Gradually, regions will form in which the density is larger, and when the process continues, such a region will beget a star, i.e. an object with a mass equivalent to $10^{5}-10^{6}$ earth-masses. Each concentration will cause a further accumulation (and larger densities) of the hydrogen. The star starts collapsing under its own gravitational pressure, with evolution acting at the nuclear level. Such regions of star-birth have been observed and photographed by Hubble, the Space-telescope. The hydrogen atoms in the star's center break down, under the gravitational pressure, with the electrons gradually separating and being pushed away from their parent atoms. The atomic nuclei – protons, neutrons, deuterons, tritons – the latter two being the nuclei of the heavier isotopes of hydrogen, with their protons bound respectively to one (in the deuteron) or two (in the triton) neutrons – all participate in high-energy collisions. Deuterons are stable, tritons decay, with a half-life of some ten years. The free neutrons are the result of scattering of the deuterons and tritons at the highest energies. The temperature keeps rising and the various particles or nuclei thus collide with each other at temperatures of tens of million degrees. Note that we thus also have the basic element for an evolutionary process, namely {\it a source of random high-energy scattering}. All we need now is an understanding of the {\it natural selection}.

To understand the selection we shall have to follow the nuclear reactions involving the following seven relevant types of particles.

"p" the proton, {\it baryon charge} (same as "atomic mass number") A=1, electric charge Q=1, 1._
{\it isospin I=1/2}, {\it third component of isospin I_{3}=+1/2}, mass "M= mc^{2}"=938.3 MeV, makes up 99.95% of the hydrogen atom's mass, spin J=1/2, sensitive to the nuclear {\it strong interaction} effective meson "glue", (such particles are called {\it hadrons} and – at the fundamental level – are made of quarks, here [uud]).

"n" the neutron, {\it baryon charge} same as proton's A=1, electric charge Q=0, {\it isospin I=1/2}, 1._
{\it third component of isospin I_{3}= -1/2}, mass (slightly heavier than proton's) M= mc^{2}=939.6 MeV, spin J=1/2, a hadron ([udd]). The neutron has an anomalous magnetic moment, but it is irrelevant to this discussion.

-"e^{-}" the electron, {\it e-lepton charge} L_{e}=1, electric charge Q=-1, mass M= 0.511 MeV, spin J=1/2, a lepton (i.e. does not sense the nuclear "glue" or "strong interaction", is not made of quarks),

"e^{+}" the positron, {\it e-lepton charge} L_{e}= -1, electric charge Q=+1, mass M= 0.511 MeV, 1._

spin J=1/2, a lepton.

"${\nu}^{0}_{e}$" the electron-neutrino, *e-lepton charge $L_{e}=1$, electric charge Q=0, mass M=0 – 17 eV,* 1._ spin J=1/2, left-handed chirality, a lepton.

"${\bar\nu}^{0}_{e}$" the electron-antineutrino, *e-lepton charge $L_{e}= -1$, electric charge Q=0, mass M=* 1._ 0-17 eV, spin J=1/2, right-handed chirality, a lepton

-"${\gamma}$" the photon, a quantum of electromagnetic radiation (light, x-rays, gamma-rays, etc.) carries no charge of any kind, spin J=1, mass M=0.

In our illustrations, hadrons are represented by a large circle, leptons by a small one, with the leptonic charge carried as a flag; electric charge is denoted by a color. Antiparticles have all their charges reversed, relatively to the relevant particles. Antiprotons and antineutrons also exist (and are created in astrophysical conditions, for instance in supernovae explosions), but they play no role in the reactions we discuss here. When a particle and its antiparticle hit each other, they may annihilate into energy (photons, for instance).

We now study the nuclear reactions. Those we present represent the first such basic set which is expected in a young new star, still composed of pure hydrogen. It was discovered by H. Bethe in the thirties. Teleologically, it makes the star act as a machine making *helium* out of hydrogen. The fundamental process can be considered as a system making one helium atom as output, from every four hydrogen atoms as input. We also list for each reaction the amount of energy freed or absorbed

The transformation of four hydrogen atoms into one helium atom is the outcome of a series of nuclear reactions; it consists essentially of various combinations of four basic reactions, which we list below,

$p + p \to {}^{2}_{1}H + {\bar e}^{+} + \nu_{e}^{0} + 0.42\ MeV$ 1._

This is the making of deuterons and also creates one positron per deuteron. Note that in the overwhelming majority of cases, the collision between two high-energy protons will end elastically, without producing a deuteron or any other nucleus. In a tiny fraction of cases, however, (1) will occur and the deuteron produced will survive the high energy collision regime. This is thus a typical evolutionary process.

The second reaction involves the deuteron – we are climbing the evolutionary ladder – i.e. this is a scattering of protons off the deuteron as target,

(2) $p + {}^{2}_{1}H \to {}^{3}_{2}He + \gamma + 5.49\ MeV$

The deuteron evolves into the nucleus of the lighter isotope of helium. The photon undergoes rescatterings and serves as equalizer with respect to the kinetic energies. The next reaction is the making of a normal helium nucleus ${}^{4}_{2}He$ in a collision between two lighter Helium isotopes, the type which is produced in reaction (2). At the same time, reaction (3) returns two protons to the original 'stock',

(3) ${}^{3}_{2}He + {}^{3}_{2}He \to {}^{4}_{2}He + 2p + 12.86\ MeV.$

Reaction (1) created a positron. It will annihilate when coming together with one of the atomic electrons, namely,

(4) ${\bar e}^{+} + e^{-} \to 2 \gamma + 1/02\ MeV$

We also need reaction (4) to operate twice, to take care of both positrons and also annihilate two of the four atomic hydrogen electrons – leaving the remaining two to fill the atomic orbits in the final helium atom. Reaction (2) should also come in sets of two, to supply the light helium nuclei for (3), and thus invests two additional protons – but we just saw in (3) two protons returned to the stock – so that in the final counting the input is still four protons (or four hydrogen atoms).

This is then the mecanism – which, at the same time supplies the star's energy output. Reactions (2) and (3) are the star's nuclear fusion engine. As against this picture, we have the reactions utilized in fusion weapons and in the designs for fusion energy reactors:

$^{2}_{1}H + ^{2}_{1}H \to ^{3}_{1}H$ + p + 4.03 MeV

$^{2}_{1}H + ^{2}_{1}H \to ^{3}_{2}H$ + n + 3.27 MeV

$^{2}_{1}H + ^{3}_{1}H \to ^{4}_{2}H$ + n + 17.6 MeV.

The latter is the $d-t$ reaction, with the highest energy production. Reaction (3) in the astrophysical process could compete and exhibits a plausible choice in nature's treatment..

Hans Bethe's "4-proton process" is just the first installment in an ascent which goes on from here. The teleonomy goes on through a great variety of reactions leading to the production of the next elements in the periodic table. The overall result consists in using as input three helium (atomic number 4) atoms and getting one carbon atom (atomic mass number 12= 3x4) as output. Nucleosynthesis goes on within stars all the way – until we reach {\it the production of iron}. In supermassive stars, the production of iron upsets that stable sequence by introducing an endogeneous reaction which {\it causes the heavy star to collapse as a supernova}. The observed frequency of supernovae explosions is roughly one per one hundred years per galaxy. In the Milky Way, our own galaxy, Chinese astronomers observed a supernova in the year 1054, which we now identify with the Crab Nebula The next case was observed by Tycho Brahe (1546-1601), the Danish astronomer (in Cassiopea, in 1572). His student Johannes Kepler observed in 1604 a supernova in Oephiochos. In 1987, the astronomers in the Southern hemisphere watched a supernova exploding in a satellite galaxy – namely the "Large Magellanic Cloud", at a distance of some 170.000 lightyears. All of these still offer the observing astronomers the impression of the terrible explosions – jets of matter blown away from the star, a residual neutron star (a pulsar) with rapid emitted pulses – a condensed object whose size is in the order of some 10 km and which consists of all atomic nuclei glued together and rotating rapidly, with unaligned magnetic field so that it behaves like a rotating searchlight.

Summing up, we note the presence of the two necessary characteristics of an evolutionary process – random high-energy collisions (the situation inside a star) and levels of (generalized) stability – the fabrication of stable nuclides. The system acquires features of self-organisation producing order, with a trail of entropy around the star. The processes are dissipative, with gravity supplying (in principle) the needs in energy. Teleonomy appears both on the strategical level – nucleosynthesis should continue until we reach the end of the Periodic Chart of the Chemical elements – and at that particular stage, the star is a machine making Helium out of Hydrogen..

At various stages of its life, the temperatures and pressures in the star evolve, reflecting changes in its composition and in the relevant processes. Astronomers will tell you, for a given star, at which stage of its life it is, by situating it in a Hertsprung-Russell diagram. This deals with mainly two parameters: the star's {\it color} (which reflects on its temperature) and its {\it size} or absolute brightness. Stars move on the diagram and one can tell its age from its location on that diagram. Various histories are possible, depending on the input. A star which is not massive enough to make a supernova will live on to become a {\it white dwarf}.This would have an earth-like size, with a mass of the order of a solar mass. The white-dwarf has a degeneracy of the electrons, i.e. it will behave like one atom (whereas a neutron-star behaves as one nucleus)

It is possible to regard these (microscopic) processes, happening at the nuclear level, as the "DNA" regulating the developments at the macroscopic (morphological) level. Nucleosynthesis can thus be regarded as controlling the star's "route" along the Hertsprung-Russell diagram. Moreover, even {\it multiplication} and {\it generations} exist in this field. The supernova explosion creates a cloud of "dust". Gravity causes concentrations to gradually evolve. Note that the heavier elements (beyond iron) are produced in the supernova explosion itself. Then, at some stage, gravity will again collect the stellar material, and one day it will become a star – in fact a "recycled" second-generation star. This can be recognized by its chemistry – the presence of the heavier elements indicate that it is at least a second-generation star (this is true of the solar system, by the way).

We open here a parenthesis, to tell the story of Steady-State Cosmology, in the context of nucleosynthesis. In the forties, one tended to assign too high figures to the Hubble constant (thus fixing a faster rate for the cosmological expansion). It therefore made the observable universe very young – about 3-4 billion years. This then created a paradox. One knows from several independent evaluations that the age of the earth is of that order, whereas the age of the Sun is in the order of 5 billion years How could stars be older than the universe? There were different ways to cope with this surprising situation. L'abb{\'e} Lemaitre found a most elegant solution. He used the cosmological constant to develop a model of a universe which had two very different phases in its history. In its first five billion years, this universe is almost static, with the cosmological constant (and its sign!) adding attraction and slowing down the expansion – or even cancelling it altogether. In its second phase, the expansion overcomes the effects of the cosmological constant – and after some time the universe becomes the expanding universe we observe.

The other solution was the Steady-State Model (SSM), ushered in by Herman Bondi, Thomas Gold and Fred Hoyle. They did away with the Big Bang altogether, assuming an infinitely aged universe. Instead of the Big Bang, matter is assumed to be created all the time, the new material emerging in the intervals between stars or galaxies. Opening parenthesis within a parenthesis, we note that such a model had been suggested once before: Leo Hebraeus, also known as Gersonides, or Rabbi Levi Ben Gerson, astronomer to the Pope in Avignon, early in the XIV century, who wrote "118 chapters on astronomy", was also the only astronomer prior to modern times to have evaluated correctly the distances to the stars (i.e. of the order of our lightyears), invented the {\it sextant}and disproved Ptolemy's epicycles model. Gersonides, though also known as an important religious philosopher, did not stick to the creation story in Genesis and arrived from his philosophical considerations at a Steady State Model, i.e. without the singularity caused by having {\it time} have a beginning. Note also that the most recent Cosmogony, known as the {\it Eternal Inflationary Universe}, which we shall have occasion to discuss in the sequel, is also a Steady State Model – yet on a grander scale.

As there was no Big Bang in the SSM, there was an urgent need to find a new place for nucleosynthesis to go on. The only possibility was in the stars – and Hoyle and coll. Started working to show that this was indeed the right place. As a result, a large effort was invested in studying how precisely did each chemical element come into being – while using the inside of stars as the nucleosynthesis laboratory. It became clear that the stars were indeed the appropriate laboratory; moreover, the picture even yielded useful new physics. At the stage where three alpha particles should make a carbon nucleus, the nuclear physics appeared to condradict this result, i.e. the carbon would not be produced at the necessary rate. Hoyle looked at the possibilities and noted that if there were a resonance in a certain specific process within the contributing system, the nucleosynthesis would be fully realized .
The process had been well studied by the nuclear physics community, which weakened Hoyle's chances of being right – but he was! As a result of studying the details of evolutionary nucleosynthesis, a new physical channel had been found, a new resonance had been discovered.

In the nineteen fifties and sixties, Hoyle's drive succeeded in enlisting a group of enthusiastic physicists, both theorists and experimentalists, who mounted a major attack on the issue of evolutionary nucleosynthesis. With William Fowler, nuclear physicist (1911-1994) whose Nobel prize, I believe, was later the expression of the scientific community's recognition of this drive, and Jesse Greenstein, astronomer, both at Caltech, and Margaret and Geoffrey Burbidge at the U. of California San Diego (La Jolla), a scientific "task force" was organized – and after a few years they had produced the "complete blueprint" of nucleosynthesis – somewhat in the grandiose manner in which the biologists are presently studying the "human genome" project. Hoyle's maverick character (especially on the British "scale") is probably the reason for the way in which he was disregarded for the Nobel prize, although he was certainly the originator and spiritual leader of the project.

Nucleosynthesis is covered by a large literature, including the basic articles of Hoyle, Fowler, Greenstein and G. and M. Burbidge. A recent popular book is by Bernard E. J. Pagel, "Nucleosynthesis and Chemical Evolution of Galaxies"[ ].

{\bf 2.2 The Anthropic Principle and Evolutionary Cosmogony}

In the previous section, we dealt with evolutionary nucleosynthesis, or the way in which Evolution produced the material content of the observable universe. In this section we display a grander ambition and ask "could the existing universe itself be the result of Evolution?". In the nineteen sixties and seventies, some ideas of that nature emerged, as a result of detailed studies of the cosmological expansion. This approach, promoted by Brandon Carter, Stephen Hawking, Frank Tipler, John Wheeler and other General Relativity theorists, came to be known as the "Anthropic Principle", emphasizing the place of Man (anthropos) in the universe.

The Anthropic Principle was suggested as an answer to several questions, the most common one being the {\it fine-tuning} issue. The equations of the expanding universe depend very much on a parameter representing the energy density, which is the source term in an equation for gravity. The expansion is governed by two effects, namely gravity, i.e. an attractive action depending on that enery-density, and the repulsion resulting from some features of spacetime itself and the cosmological constant.
The dependence on the energy-density is not a smooth one. If the energy-density is somewhat larger than the {\it critical} value, the gravitational attraction wins and the universal expansion stops within months or at most a few years, after which it is replaced by collapse. If, on the other hand, the energy density is somewhat smaller than the critical value, the expansion is very rapid and the energy-density diminishes very fast. This universe will have no stars and no matter beyond hydrogen or quarks – since there will be no chance of regrouping or of nucleosynthesis to start.As a result of these considerations, it is essential that the energy-density should have its critical value, for any evolution of matter to occur. This issue is known as the {\it fine-tuning} problem.

The possibility of introducing evolutionary considerations is obvious here: suppose that 99.999% of the Big Bangs do yield non-critical values for the energy-density, prior to the explosion – yielding "universes" which last a few hours, before either recollapsing completely or dispersing completely without even starting nucleosynthesis. This may have happened a billion times – until one day, by pure chance, the energy-density will happen to have the critical value. This universe will have good chances of survival; it may even evolve some intelligent race, with scientists which will become interested in Evolution.. The birth of the Universe becomes an evolutionary process, with randomness entering in the value of the primordial energy-density, and for "good" values, structural order (or self-organisation) will increase. This idea can be generalized: whenever a pre-Big Bang parameter requires fine-tuning, we may assume that the good (fine-tuned) values are the result of an exceptional "throw of the dice". As we know that we exist and are surrounded by a flourishing universe, we may assume that {\it all the parameters have 'critical' values "because" we exist}. This is close to an evolutionary ansatz – but it is also very close to the statement {\it "all these parameters have these critical values in order that humanity might exist"}, which can also be said in a slightly different choice of words {\it "these parameters have their critical values for the sake of humanity"}.At this point, nothing is left of the Copernican ansatz and it would seem that man returns to his pre-Copernik position. As long as one's ideology assumes that billions of universes were tried and failed until we got this one – all in an evolutionary spirit – we are using the {\it weak anthropic principle}. If we adopt the view which claims that it all occurs for our sake – we are assuming the {\it strong anthropic principle}.

The adepts of the weak anthropic principle have one result which does not derive from anything else.

They can explain why we do not find other intelligent races in the universe. Humanity has appeared on the scene after 12-15 billion years after the Big Bang. If this is the necessary time, the chances that yet another race would have reached the same stage are very small. There is a literature dealing with the Anthropic Principle, including books and collections by Barrow and Tipler [ ], Bertola and Curi [ ], and numerous articles.

In the case of the critical energy-density, we know from the theory about the necessity of fine-tuning. However, once we base our treatment on the "lucky throw (but expected)" ansatz, there is not much that we can do about the critical values – we have them from the theory anyhow. Note that I have added "expected" because we know that if it were not for this lucky throw, we would not be here. However, when applying to cosmological history the physics of "the Standard Model", we learn that all parameters – such as the electric charge on the electron, the Fermi constant of the Weak Interactions, the QCD coupling α_{s}, or Newton's gravitational constant G_{N} - all of these must have been "selected" by the dynamics of the Big Bang or of the following (very early) period in the history of this universe. .

The new idea stems from a development in Cosmogony and the adoption of Andre Linde's version of {\it Eternal Inflationary Cosmology}. This now provides precisely for as many Big Bangs as you wish, i.e. a randomized true evolutionary lottery. In this spirit, one may look at evolution more seriously, including {\it procreation} and thus further generations. One can also generalize the physical picture, adding all symmetry and symmetry-breaking parameters to the evolutionary machinery. {\it All of this is not forced on us, in the way we were forced to act in the case of the energy-density}. It is more a matter of exploring and looking for further insights.

Eternal Inflation yields one more clue. The birth of a new universe is the result of a small black hole being created in an existing universe and tunneling out as a seed for the new universe. One may therefore assume that the greater the capacity of an existing universe to make black holes, the better its chances of having offspring. This then also guarantees that the most "common" type of universe will naturally provide for fine-tuning, etc. . An objective program can thus be developed, to test whether a small change in any of the listed parameters would cause our mechanisms to produce {\it more} or {\it less} black holes.. Should the answer be 'more', there would be. no correlation between this problem and the evolutionary drive. A 'less' or 'no' would confirm our interpretation. What put us in a better position than in the past is the Eternal Inflation Model..

Note that the entire Inflationary Model was devised (1981) as a solution to several problems, one of which was the fine-tuning issue. Moreover, it contains the gravitational mechanism producing the cosmological expansion, a "de Sitter" model. This model has the property that the gravitational (negative) binding energy precisely cancels the potential energy of mc^{2}. Issues resolved by Inflationary Cosmology include the {\it horizons} paradox (in an expansion from a spacelike distribution shape) namely – it is impossible to explain similarities between zones which could never have had causal contacts, the monopoles/zones paradox (where are the barriers between zones of different symmetry breaking ?), and the fine-tuning and flatness paradox. The making of yet another "universe" or more precisely, of another connected 4-dimensional sheet, in the future universe – requires the random growth of a vacuum fluctuation ΔE of Planck energy $(10^{19}GeV)$ self-sustaining during a time-interval Δt; on a special occasion, the energy-density will be Planck density – the ΔE occupying a cube with sides of Planck length ($10^{-32}cm $.This energy fluctuation makes a tiny black hole. For a frame within the minihole, the contraction will become an expansion and a new sub-universe will grow from these modest beginnings.

Returning to our evolutionary universe, whose progeny's existence will depend on its own capacity to make black-holes, Lee Smolin (of Penn State University) conceived this idea and has since investigated the model in this Popperian spirit. Checking the effects of a change in the value of the proton-neutron mass difference (e.g. reversing these values, making the proton heavier) Smolin found corroboration with the evolutionary ansatz. Had the neutrons been the lighter, there would have been no electriically bound atoms – and for the same reason also no accumulating matter, no stars and thus also no black holes! Two other parameters give similar results. Smolin has developed these ideas in a book, though with a sales-increasing sensationalist replacement of "evolutionary" by "living"; in his title "The Life of the Cosmos". Following an evolutionary mechanism does simulate life – but so do nucleosynthesis, stellar evolution, and all other sectors described in this book

Smolin's physically constructed model is not the only imaginative suggestion along these lines.

Harrison [ ] has suggested a similar scheme, except that his version manages to have {\it humans} (or their ETI analogs) play a role in the evolutionary sequence. In the study of universe-creation that went on in the 1980s, at least.one calculation was presented under the (tongue-in-cheek) title "Creation of a Universe in the Laboratory" [ ]. Harrison exploited this type of result by having the "humans" of the "old" universe produce the new universe. Since making humans requires the existence of condensed matter, the conclusions are roughly the same as in Smolin's model.

{\bf Chapter 3. The Emergence of Life}

{\bf 3.1 The Making of the First Organic Molecules}

Let us review the present status of the research programs dealing with the beginnings of life. Up to the XIXth Century, scientific opinion had adopted the view according to which, "life creates itself" and paleontological remains were assumed to represent incomplete attempts of that nature. Presently, the above wording would still befit the overall picture – but in a totally different context, the Darwinian.

Those same fossils are now known to represent the fullness of life throughout three and a half billion years. Geological, paleontological and biological research have given us a fairly complete description of the story of life on our planet and molecular biology may yet achieve an expertise sufficient for success in bringing the dinosaurs back to life, following Stephen Spielberg's "Jurassic Park".. There is, indeed, a present program studying fossil DNA.. Moreover, the successful {\it cloning} of 'Dolly' the sheep from another sheep's DNA represents a success in the same direction.

It was mainly Louis Pasteur (1822-1895) who managed to invalidate the traditional view about "life generating itself" which assumed that microbes appear "naturally" in a Petrie dish, by "self-creation". Pasteur assumed that microbes might even transit through the surrounding air, just being carried over by the wind etc.. He accordingly arranged for the dish' s opening to be "S" shaped – and there were no more "self-created" microbes after that.

In the present search for "elementary life" one is after the creation of primitive cells, in fact – on the one hand, a metabolism – and at the same time, another search is after propagation (or multiplication). For metabolism, some of the earliest organic compounds had to be available, in order to enable the primitive organisms to produce {\it proteins}, chains of some twenty amino-acids, from which the enzymes could then form – and might then take over the control of that metabolism. The discovery of the DNA's {\it double-helix}structure and of the genetic code, has made it clear that propagation also requires the availability of {\it nucleotides}, spanning the DNA's double-helix. Several ways have been suggested for the making of these "basic bricks". During the first few hundred-million years of the Earth's history, its atmosphere was made of hydrogen, plus the gases methane (CH_{4}), ammonia (NH_{3}) and CO_{2}. In 1952, Stanley Miller, then a graduate student, put a mix of these four gases in a test-tube and arranged for an electrical discharge to be fired through the mix – a reaction made to resemble the effects of lightning in the earth's early atmosphere. The result was a success, with the amino-acids indeed forming in the test-tube. Note that there is also an alternative (or just an additional possibility), namely having the same key constituents forming as solutions in the primeval oceans.

The making of a living cell out of these primary constituents turns out to be more complicated. This is a phase which could have lasted 200 million years; we find in nature single cell beings which have been richly endowed, with DNA, RNA, etc, about 3.5 billion years ago. Earth formed four billion years ago – but one has also to allocate a few hundred million years for its cooling down and crystallizing.

{\bf 3.2 Autocatalytic Processes and Oparin's Conjecture.}

From the moment the key compounds have been produced, the rate of advance is set by the processes in which these compounds manage to encounter their likes and build up – first more complicated compounds – and then the living cell itself. For the first part of this "program", the Russian biologist Alexander Oparin has suggested an interesting solution. He showed that a type of {\it jell} will form very easily, and this jell will preserve the organic compounds and protect them while they will be crowding more and more densely. There were other difficulties arising around the jell solution – such as the rise of osmotic pressure, which might endanger the entire system – except that it was found that the amino-acids produce polypeptids, and the latter open "channels" in the jell.

The next problem is the rate at which the system's advance is progressing. Catalysis is essential, otherwise the entire program is too slow. What is now studied in detail is the systems of {\it autocatalytic} reactions. It turns out that more and more of the organic molecules, which form from the basic compounds, are endowed with catalytic properties with respect to other compounds in the set.
The more such compounds are present, the higher the chance that any one of them will have catalytic effects on some of the other processes.

The study of such systems is done first in the abstract, mostly in computer games. In these games, a compound appears as a "button" and a reaction between two compounds is represented by a "wire" adjoining two "buttons"and issueing yet another wire, leading to a new button (representing the resulting compound). Should one of these buttons (i.e. compounds) have catalytic power with respect to another reaction, it will be represented by a wire with a different color, which will connect the catalyser with the wire representing that accelerated reaction (between any two other compounds). The wire representing the assisted reaction then gets a different color (or a different width).

To start with, one assumes a tiny probability (say 1: 1.000.000) for a given compound to have some catalytic value, and the computer game is launched. It turns out that as the number of buttons (compounds) increases, and as the number of wires approaches the number of buttons, the better the chances for an autocatalytic system to develop and continue on its own – provided the supply of the original buttons is assured.

Even without involving catalytic action, if we connect at every "step" any two buttons in the set, at a certain point one witnesses a {\it phase transition}, i.e. a change like the transition between solid and liquid phases (e.g. ice to water, or water to water vapour).. This happens roughly when the number of wires is about one half of the number of buttons. At each step, one also counts how many buttons are connected to any one button on the average. It might happen, for instance, that there are still very many which are not yet connected at all. There may also be many cases of just two buttons making a connected pair – which is otherwise disconnected from the great mass of buttons – or of "triplets", i.e. three buttons connected along a string. When the number of wires attains roughly a half of the number of buttons, one notices how at each step one now sees connected bunches getting tied up together – and after a limited number of further steps, almost all buttons have become connected, making up a huge knot.

All of this occurs even faster, once we add catalytic self-acceleration. As I mentioned, this is as yet only seen in computer games. Stuart Kauffman, the American biologist whom we mentioned in the context of self-organisation, has predicted that within a few tens of years, it will be possible to see all of this in real reactions. That will be the day when we shall be watching the creation of life in the lab…

Part II: Ethics and Evolution:

Introduction. The "Judeo-Christian Ethic" and the von Humboldt Brothers.}

Back in the fifties, reading F. Nietzsche's poetic {\it Thus Spake Zarathustra}[5], I had been impressed by its combination of literary beauty with bare cruelty, praise for the strong and spite for the weak. I had also noticed {\it en passant} the references to evolution. I had originally intended to address the Humboldt meeting on an interdisciplinary topic -- my thesis about the role of research in the evolution of society, as a randomness-inducing mechanism. Instead, I decided I had first to understand how Nietzsche (1844-1900), in his reliance on evolution for a message of cruelty, appears to run so strongly counter the humanistic ethic and the whole direction in which the evolution of human ideas is carrying us -- witness the present involvement in the environment and efforts to preserve endangered animal species..

Gradually, I came to realize how Nietzsche had misunderstood the message of Darwinism, thinking only of the {\it survival of the fittest} {\bf biological organism}, whereas ethics relate to human societies, where there is another evolutionary process which becomes relevant. I presented my case in that Humboldt lecture. A further search of the literature later revealed that geneticists such as Hamilton had already indirectly partly detected the error, within the context of the evolutionary advantages of altruism, still at the biological level itself. Both Nietzsche and Julian Huxley (who had agreed with Nietzsche's interpretation of the {\it survival of the fittest} -- but had pointed to man's {\it "having to rise above evolution"}) had misread the message, especially when considering the generalization to societies. I ended up publishing an article on this subject in the {\it Journal of Social and Evolutionary Studies} [6]. This material thus relates to the evolution of human societies and I have covered it too in Part II.

There is an anecdotal footnote to this analysis of the spiritual foundations of Nazi antisemitic "ethics" in the context of a Humboldt lecture. The brothers Wilhelm (1767-1835) and Alexander (1769-1859) von Humboldt grew up in Berlin in an atmosphere of culture, actively participating in the learned and liberal-oriented {\it salons} of two Jewish ladies, Henriette Hertz and Rachel Levin. It was Wilhelm, the pioneer linguist, who in 1809-1811, as Minister of Culture and Education, abolished the "oath of allegiance" which a university professor in Prussia had to take upon his appointment, swearing with his hand on a copy of the New Testament, an act which was considered by both sides as effectively abjuring the Jewish faith and converting to Christianity. It was because of this oath that Jews could not hold academic positions without converting. The great mathematician and physicist K.G. J. Jacobi was the first Jewish scientist in the modern era who profited from W. v. Humboldt's reform and, though still a young man, was endowed with a prestigious Royal Chair, without converting. Years later however, in 1848, the politically liberal-leaning Jacobi signed a petition to the King of Prussia, asking him to desist himself of some of his prerogatives in favor of Parliament. The king immediately cancelled Jacobi's Chair and the mathematician found himself in the street, with a wife and seven children to feed. After a few months, when the dust had settled, Alexander von Humboldt, the geographer and explorer of the American continent, went to see the king and asked him to pardon Jacobi's liberal escapade. This, the king agreed to do; however, the oath had meanwhile been reinstated by one of Wilhelm von Humboldt's successors. Jacobi duly swore and abjured his Jewish faith.. Closing the parenthesis, I think the Humboldt brothers would have been happy with the ethical content of my 1983 Humboldt lecture. Also, since 1992 there is a Humboldt program encouraging Israeli-German academic collaboration, similar in its content to the German-American program. The Humboldt brothers must be smiling.

Abstract
{\it Societies} exist already in the context of biological evolution, and even among amoebas. Among some insects, the societies are functional. We shall explain Nietzsche's error, in relying on {\it "the war of the species"}plus Darwinist competition – with the conclusion, in the spirit of the {\it survival of the fittest}and a rejection of "weakness", of {\it self sacrifice} and of {\it pity} – notions which were rejected by the Nazis too. We note that birds and mammals protect and defend their young, with a readiness for personal sacrifice, if necessary. We shall analyze the origins of {\it altruism} among the animals.It is in analyzing the conclusions with respect to {\it humanity}, that we thus encounter {\it man} – an animal capable of building tools and of communicating . Note that communication is an essential element of stability, with respect to the making of tools, over the generations. For man, a social animal with a well-developed brain, it is possible to replace (or strengthen) the genetic heritage by an educational-cultural heritage. The last hundred thousand years have indeed seen mankind's evolutionary development switch from the genetic to the cultural.

. . Chapter 4 : Where did Nietzsche Go Wrong?

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{\bf 4.1 Nietzsche's Superman}

Darwin's ideas strongly impressed the XIXth century philosophers. Considering that this was still Darwinism without any kind of mechanism (only gradually did the genetic aspect add itself, but the structure of DNA was only understood one hundred years later) only the motto, {\it "survival of the fittest"}, invented by the English philosopher Herbert Spencer, caught on. "Fit" can have various meanings in English, but it was natural that in this context the word "fittest" came to mean "the strongest", which is also its meaning nowadays, especially as it is used among sports reporters discussing the state and prospects of an athlete or a player, before an important game, for instance. Summarizing, we note that the implications are in favor of strength, of force, and are certainly not in line with the message of Christianity or, some seven centuries earlier, with that of the Biblical prophets, such as Isaiah or Amos. Western culture is inbued with the message of social justice, emanating from these sources and it was precisely against these messages that Nietzsche rose..

Friedrich Nietzsche (1844-1900) did not know that he was preparing the foundations of a doctrine, one that could realize anything that went with cruelty and hatreds. The Nazis indeed liked to use him as justification for their eugenics, or for their antisemitic activities. They decided who would come under the {\it unfit} classification. There have been claims that Nietzsche himself was not antisemitic, and his sister has been blamed for any antisemitic statement of his. We know, however, that he "declared war" on Judaism, blaming it, as the original doctrine which set the foundations of the Christian faith.

Except for the sub-field of Logic, Philosophy, as a discipline, does not carry a responsibility for clear-cut positions and mathematically precise statements. Often, there is a poetic background and rhythm or rhyme take precedence over clarity. Many modern philosophers have also been prominent in the aesthetic presentation of their message. Sometime, the poetic aspect encourages them in setting an atmosphere of ambiguity – the precise contrary of the monovalence favored by a scientific discourse. As a result, one has ceased to search for clarity. To each his Nietzsche, while some in the younger generation have even elected to have Nietzsche at the center of their Pantheon. He is considered as the leader of the rebellion against Rationalism, almost a reincarnation of Christ. In France, for example, the present generation of philosophers regard themselves as "Nietzscheans" and/or "deconstructionists" (in other words "destructionists") and have, as such, dominated the scene since the Sixties, with just now, at the end of the Century, a movement rising against their influence.

Let us return to the evolutionary aspects. Here are some passages from "Thus spoke Zarathustra",

"I teach you the Superman" (i.e. a genetically more advanced human).."all beings which evolved till now, also created something more refined then them."

"I teach people to say NO! to anything representing weakness and fatigue, to say YES to all that represents power, force."

"Nice qualities, giving up pleasures or interests, having pity – and even the readiness to self-sacrifice all of these are notions emitted by exhausted people" 1._
and in "Twilight of the Gods" he continues,

"People actually named "God" everything which induces WEAKNESS. The juridical sentence in which destiny, orders the weak to agonize and to die, should be respected"

and in his "Antichrist" he writes,
"Psychologically, the Jewish nation is a people endowed with a stubborn will to live. When that nation found itself under impossible conditions, it decided – out of its own will and out of the cleverness of its self-defence – to side with all base and decadent instincts – though without exposing itself to them. The Jews realized the hidden power which goes with these and understood that with such weapons they could beat the world".

Note that Nietzsche finished "Zarathustra" shortly prior to his hospitalization in a mental health establishment (1889). Excerpt from Nietzsche's diary (in Vienna), "April 8th. I pissed into my boot and drank the content", which makes it clear that he was not his normal self. And yet his teachings influenced many and were very much what the Nazis were looking for. Note, however, that I have come across contemporary Christian philosophers who stick to Nietzsche, to the Nietzsche of "Ecce Homo"presumably, who regards himself as Christ's continuator (while also "updating" the message). Such Christians really love the man. At worst, he is regarded as a hero, breaking conventions, an iconoclast – with a very few who are shocked by the aggressivity of the message.

{\bf 4.2 Nietzsche's and Huxley's Interpretations of the "fittest" in Darwin's Message}.

One would like to know whether or not "the theory of Evolution", in its Neo-Darwinian version, indeed preaches a message of {\it brutality}, of {\it aggressiveness} – arising directly from its motto of {\it survival of the fittest}. Note that should this view prove to be correct, there would still be room for further deliberation. This was the view of at least one expert, Sir Julian Huxley (1887-1975), who, aside from being the grandson of Sir Thomas Huxley (1825-1895) -- Darwin's collaborator, perhaps the most important one – was a distinguished biologist in his own right. Note, however, another somewhat relevant family link – Julian Huxley was the brother of Aldous Huxley (1894-1963), the author of (among other books) the "Brave New World", a science-fiction novel with biological aspects. It seems to me (I read the novel when it was published) that it was mainly the issue of {\it cloning people}, which worried Aldous Huxley some sixty years before the 1997 cloning of the sheep Dolly, which resulted in the present full public awareness of that issue.

In a 1943 lecture, Julian Huxley assumes indeed that the message from Evolution does consist in a vindication of {\it force}, perhaps even of brutality and aggressiveness. His call, however, is {\it for man to dissociate himself from Evolution in this context "in a courageous anti-evolutionary decision"}. Huxley would like to see "a victory of man's nature over mother nature's brutality". There is no doubt – Huxley and Nietzsche both believed that "mother nature" favors the strong and the brutal. The difference is that Nietzsche preaches obedience (i.e. that man should indeed follow the call to strength – with its sequel of brutality and aggression) whereas Huxley preaches rebellion.

In what follows, I present a view [ ] which opposes both Huxley and Nietzsche, in their reading the message of Evolution. I claim that both erred in concluding that the competitive nature characterizing evolutionary processes in nature also implies a similar approach in inter-human relations – or even in the relationship between man and the other living beings who share this planet with us.
Nietzsche, as we saw, put the blame on Judaism, as the mother-doctrine to Christianity. These gospels,

he said, poisoned the pure, unsuspecting Arian man. I shall not enter into the theological discussion dealing with Nietzsche's association of Judaism with Christianity – other than a reminder of the historical sequence. I am setting aside such episodes as the Inquisition, the crusade massacres, etc., assuming that what we mean by "the Judeo-Christian ethic" is the "intersection" of the two doctrines (i.e. the part that is common to both religions). Alternatively, for a more poetic description of this "intersection", we may use the poetic envelope which carries that ethical content, in the Hebrew and Yiddish writer Y.L. Peretz' short story "If not even higher than that". On the French literature side, we could couple Peretz with the French author Gustave Flaubert, in the latter's short story {\it La Legende de Saint Julien l'hospitalier}. The two do represent a similar common thrust.

Does the message of evolution indeed encourage force, as claimed by both Nietzsche and Huxley; do human ethics then represent a human rebellion against the pragmatism of the evolutionary doctrine? I claim that taking this line of thought is equivalent to the assumption of a much weaker evolutionary drive. Man is also a part of nature, so how could the making of man produce a view (pity, clemency, etc) so contrary to evolution's message?

Man is also a part of nature – and yet evolution has included in man's make up some strong "altruistic00" features. These are just as much a gift of "nature" as the fact that we have five fingers. Some of these features we share with other mammals or even birds, such as the protection of babies or children, in the course of which the parent often risks his or her life. But my claim goes further than that. The notions we include under the title of "human conscience" have also arisen "naturally". Even the motivation for Huxley's suggested rebellion against the brutal aspects of the "survival of the fittest" must have been induced by evolution!

{\it I claim that altruism, pity and even the readiness to risk self-sacrifice, all such features are the result of evolutionary processes}. Moreover, these features are interconnected. The risk of self-sacrifice in the course of childcare is related to the readiness of hundreds of thousands of soldiers to risk their life for their "motherland" (the term fits better than "country", in this context). Both are evolutionarily developed altruisms.

My claim is motivated by the fact that {\it evolution works on all levels simultaneously,} sometime evolving the social layer while developments also occur at the level of the organism. Both Huxley and Nietzsche were following evolution at the level of the individual organism and missed its action at other levels, such as the social. Let us look again at that phrase – the survival of the fittest – this should happen at several levels in parallel – the fittest organism, the fittest clan, the fittest society. In modern science, the hand of evolution has been identified at all levels, not just at the biological. The fact that many species of insects operate as organized functional societies – this fact is as much a result of evolutionary developments as any feature in the body of an organism (say the kangaroo's pouch). After all, in the previous chapters of this book, we have reviewed the doings of evolution at various levels, going from the universe down to the chemical elements, from stars to galaxies. Nucleosynthesis is going on, in stars, all the time. What about the evolution of animal societies, whether functional as with the best known insect societies – ants or bees – or on other models – do these have to wait first till the evolution of the organism terminates? Clearly, the levels are interconnected, with evolution working at all levels in parallel. We have looked at the ingredients making up the evolutionary action in detail in Part I of this book (randomized mutations, selection criteria) and also at the characteristics of such groups (dissipation, self-organisation, teleonomy, and in advanced cases, propagation).

With the arrival of {\it homo sapiens} on the scene, evolution has been active at the social level It is possible that biological evolution is going on without our having detected its action. If it does, it is happening with an extremely slow timetable. The transition from Neanderthal to Sapiens took several hundred thousand years. In the last hundred thousand years there was no mutation of an important nature in the biology of sapiens. On the other hand, what an evolution on the social level – and look at the rate. Taking just one example – the first human flight occured in 1903 – and by 1969 man had landed on the moon! In the coming section we shall look at social evolution and identify the emergence of altruism and related notions.

{\bf 4.3 Animal Societies and Genetic Altruism}

Already at the amoebas' level, evolution was able to open a parallel path, the path of social evolution. There is one basic requirement for this to be possible, namely {\it communication}. At the amoeba's level, one frequent solution takes on a chemical character. Taking as an example bacteria living in a liquid matrix, the individual bacterium can produce and spread a {\it communication-substance}into the immediate environment. Each of the bacteria moves in the direction in which the communication compound's density appears to increase. This also ensures the stability of the swarm in its generic motion. Communication substances may consist in a powder, which is spread by each amoeba into its immediate neighborhood, or a liquid, poured into a liquid matrix (in water animals, for instance), as previously mentioned.

Redirecting our attention higher up in the animal kingdom, we come to the insects, for instance. They include species with an organized family cell – parents who nurture and protect their young – and also the typical and well-known functional societies, such as the ants or the bees. In all these cases, genetic heredity includes the knowledge and means for both communication and specific action, as related to the function of each individual within the functional organisation. This includes the altruistic actions – such as the self-sacrifice of the soldier ants when defending the queen, or just caring about the eggs or nourishing the larvae. Summing up, we may state that {\it the survival of the genus or species is given a higher priority than the survival of the individual}.

The capacity for communication opens wide horizons for evolution, in exploiting the possibilities of cooperative action. The information relating to these evolutionary activities is inscribed into the species' DNA at an early stage. Note that the importance of altruism is in fact one reason for evolution to have chosen the social path. The basic factor is the lack of any other solution to the problem of caring and protecting the young, as long as they are not capable of caring for themselves. This issue reaches the other end of the animal kingdom. The lioness protecting her cubs with all she can give – this is the only solution nature has found for the perpetuation of the lion species.

A German zoologist, Dr Anna Rasa (then teaching at Bayreuth) followed a group of mongooses in the Tara desert in Kenya, witnessing how the entire clan tried to help one mongoose, wounded by some larger animal. The group waited six days for the wounded mongoose to be able to come along, which he then did.

In his 1963 Ph.D. thesis, the British naturalist W.D. Hamilton studied the emergence of altruistic behavior. His research was comprehensive and included activities beyond our examples of care and protection of the young or of soldier insects fighting to defend the queen or her eggs. His thesis is in itself an answer both to Huxley and to Nietzsche. Note that all of this, though involving the social level, is operating through information inscribed genetically, i.e. in the individual's DNA.

{\bf 4.4 Altruistic Behavior Induced through the Cultural Heritage}

In the animal kingdom, the only way evolution can ensure the transmission of information necessary for a specific program is to do it genetically. Everything that prepares the organism for a specific action must be supplied by the genes, be it those of the lioness or those of a soldier ant. When we come to man, however, new possibilities for the encoding of such information are available. This function is performed by the cultural heritage – education, books, customs, art – every one of these may be appropriate for the specific need. Castors build impressive dams on rivers – with engineering knowledge which they get through their genes. Human dam builders get their knowledge from a University's School of Engineering.

The cultural memory of the average citizen of the Western World does indeed contain the messages relating to pity, clemency, humanism, etc., the Judeo-Christian indoctrination that Nietzsche disliked so much. Socialism was invented and developed in the XIXth century and added some generalizations of the notions of mutual help etc.. This message grows in stages – in this century, for instance, we are gradually broadening the definitions so as to include the animal species which cohabit the earth (minus those who endanger man – such as microbes etc) with us – and the environment itself. Note, however, that it is not clear that this message of a broader humanism has really caught. The fact that such a state as Nazi Germany could develop in this century would tend to indicate that the message has not really caught.

Objectively, the humanistic solution is really "the fittest" because {\it the strength of a chain is that of its weakest link}. Soldiers will fight better when they know that if they are wounded, they will be rescued and taken to a hospital. History tells us that other methods have been tried: The Spartans "eliminated" babies who appeared weak or ailing, the Eskimos exposed their elder citizen. Altruism is an evolutionary feature and is transmitted genetically in animals. For humans, the Judeo-Christian doctrine Nietzsche so despised carries the message and is therefore an evolutionary asset for the strength of a society.

Part III: “Progress” or the Evolution of Society

Introduction

In preparing my presentation for that 1977 Caltech Fairchild Symposium on Relevance, I had one of these moments of clarity {"on a clear day you can see forever"} which is and has been experienced by any researcher at the moment of discovery -- sometimes also, unfortunately, an illusionary discovery.. I remember Kepler's description of his excitement at his insight according to which the planetary orbits correspond to a sequential embedding of the five perfect solids, in Russian Babushka style... We do not know whether he experienced anything similar when he discovered the less aesthetic but correct reading of the pattern, namely the marvelous {\it three laws of planetary motion} which gave Newton material, abstracted from phenomenology, with which to build a real theory...

Whatever the value of my relevant moment of insight in 1977 in this context, this is when I first perceived my interpretation of the role of research in society's progress and of the dangers deriving consequently from attempts to over-direct it, even when guided by Hilbert's principle. I collected examples and more extensive case studies and lectured on the subject in a 1979 lecture tour in Mexico and Venezuela. The talk at IVIC was taped and I edited it, so that my first presentation of the subject in print appears, in English, in The Venezuelan publication {\it Acta Cientifica Venezolana} [3] -- and in Spanish in a Mexican publication. I continued to search for case studies and published some of the new material in a medical publication, {\it Metabolic, Pediatric and Systemic Ophthalmology} [4], in an issue dedicated to the memory of my friend and colleague Rudolph Stein. This is the view I am presenting in Part II of this book. My main thesis is that the more "important" the discovery and the more extensive the evolutionary jump, it will cause in the development of human society (and perhaps also in science itself), {\it the less predictable it is and beyond controllability through the Hilbert - Alvin Weinberg relevance mechanism}. I bring (hopefully) convincing examples.

Abstract

The "genetic code" of human societies is enciphered in man's cultural heritage. The "stable levels" in the evolution of mankind correspond to the sweeping introduction of new {\it technologies}. This is how we classify the pre-historical eras . This is also how we have classified the stone age itself, i.e. into paleolithic ('old stone') and neolithic ('new stone'), i.e. the 'older' stone is 'natural', while the 'new' one has undergone some sharpening procedure. The stone tools are later replaced by {\it copper}, then come the {\it age of bronze}, the {\iron age}, the {\it industrial age}, and we have surely entered {\it the age of information} or the {\it age of computers}.

New technologies are thus characterizing the stable levels of social evolution. Where then is the {\it randomized mechanism} supplying the mutations? These are the scientific or technological innovations, whether they do represent scientific discoveries or just an innovation facilitating the adoption of a new technology. In modern times, {\it this is powered by the advance of science}. We shall study a large number of discoveries. The most surprising such case is probably the story of the modern computer, with the startline in the beginning of the XXth Century, in the discussion relating to the {\it Russell – Whitehead paradox}. This esoteric discussion led to the {\it Universal Turing Machine} and somewhat later, in a world at war, to the modern computer. Another example is the discovery of the extraction of Nuclear Energy, through nuclear fission, between 1938 and 1942. And yet another good reason to study this example relates to the 1934 statement by Lord Rutherford of Nelson, discoverer of the atomic nucleus, who declared that {\it whoever should happen to believe that this nuclear energy will some day be extracted and utilized is having a pipe-dream}. We shall study the conclusions with respect to setting national targets for research – and review failures in countries which had tried to dictate programs to their research establishments.

{\bf Chapter 5: The Role of Scientific Research in the Evolution of Society}

{\it 5.1 If this is Evolution, where is the randomized mutation?}

We continue researching the evolution of societies, analyzing the processes which contribute to the end-product. Let us first identify the "stable levels" reached by the evolutionary program or procedure – step by step. We are dealing with societies about which we are (roughly) informed. We start – as usual – with the Paleolithic Period (the Older Stone Age) then follow with the Neolithic (the age of "the new stone".- meaning that the stone knives were sharpened through a technical procedure). Next comes the "Chalcolithic"(copper) and then the Bronze Age, followed by the Iron Age (starting around 1000 BC). Writing was developed during the Chalcolithic and the Bronze Age. It became alphabetic during the Iron Age. The Bronze and Iron Ages take us into History, since writing was now available and developing fast. It is relatively easy to identify the characteristics of the periods we have listed: it is always a {\it technological innovation !}. The classification evolved by the historians defines and links the various periods according to the availability and exploitation of a new technology. Note that the present period is again a transition, from the Age of Industry into the Age of Information. No doubt that further developments will follow the same line – a new technology is indeed a formidable lever for progress. One feature, which may serve as an example, is the demography. It has evolved in jumps, with technological transitions. It received a boost, in Europe, in the Age of Discovery, itself triggered by the West's "discovery" of the compass, traditionally described as an import from China – though this is presently regarded as less authenticated than the other imports from the Far East, namely {\it printing, gunpowder, noodles and oranges}. One result of {\it geographical} exploration, is the introduction in Europe of the culture of corn – imported from newly-discovered America. The demography thereby incurred a first large jump. It jumped again in the Industrial Age, towards the end of the XVIIIth Century – George Stephenson (1781 – 1848) and James Watt (1736 – 1819), following the scientific rediscovery of the steam engine, as a result of progress in physics in the XVIIth Century – Robert Boyle (1627 – 1691), Edm\'e Mariotte (1620 – 1684). The third great rise in the European population – and then of the rest of the world – followed from the progress in public hygiene, as a result of Louis Pasteur's (1822 - 1895) medical or microbiological research and initiative.

Question: this is certainly an evolutionary theme, a series of consecutive levels achieved in a teleonomic sequence. However, stable levels represent the outcome of evolution, but they should occur as the result of a system of random mutations. Where are these?

{\bf 5.2 The Discovery of Penicillin}
It is precisely the answer we give to this question which is also the most important "message" of this book. We claim that scientific and technological innovation do not follow a routine causal path. A "discovery" which is still predictable, only represents a limited extrapolation from the present research front. Important discoveries are real surprises and cannot be either expected or predicted. We do not know who invented the wheel, but I am pretty certain that it was not a matter of somebody sitting down with a drawing compass and drawing paper, to design a new kind of practical help to transportation. Most probably it started with somebody noticing a tree trunk (or a round stone) rolling down a slope, perhaps with a child sitting on the tree trunk. This may have occurred several times in the past, without anybody being impressed, but on that specific occasion, our imaginary observer brought the idea to the attention of whoever was responsible for the transportation of heavy loads..In fact, this is how the megaliths were carried over to Stonehenge in England (by rolling them over tree trunks), in the middle of the Third Millenium BC. The discovery of penicillin by Fleming (1881 - 1955), Chain and Flory was a similar case. One day, Sir Alexander Fleming, leaving his lab in the evening, closed a "Petrie Dish" (with a bacterial culture in it), apparently without making sure that the closure be tight. Checking the next morning, he found that the bacteria were dead. This same story may have occured many times before, with the scientist just promising (himself or to others) to improve the closure and add some protective measures. In the case of Fleming, the death of the bacteria made him curious about an agent which could kill bacteria. He investigated and noticed the mold which had grown on the lid. The final result (with help from Ernst B. Chain (1906 – 1979) and Paul J. Flory (1910 - 1985) was {\it the discovery of penicillin and of antibiotics} – certainly one of the most important discoveries of this century, as far as human society is concerned. Since this discovery, the antibiotics form a specially important research area, but nobody could have predicted that first result. One cannot predict a "really important" discovery – because by its very nature one would not know that it exists. As a result, scientific and technological discoveries make up the random acquisition of innovative technologies, some of which raise society unto a new level of evolution.

{\bf 5.3 Greek Science and Columbus' Discovery of America}

Ancient Greek science reached a high level before its demise, the latter occuring mainly as a result of the emergence of Christianity and the Judeo-Christian religious ideology. These aethical pursuits drew away the attention of the intellectual elites. At the same time the involvement in scientific research was equated with paganism. Instead, after Philo, the Alexandrine Jewish philosopher, had presented a thesis claiming that Greek philosophy carries the same (moral) message as the Bible, the conciliatory adepts felt obligated to point to one document as "the" philosophical thesis. They indeed selected one of Aristotles' books (whose style fitted the idea of a summary) as the piece that needed to be appended to the holy writings in order to "complete" them. This is how Greek scientific research stopped – while a partial Aristotelian summary became dogma (and was accepted likewise by both the Moslem and Jewish leaderships).

For my present example we should note several important results, from among the list of achievements of Greek Science. Euclid's geometry was both in itself a great achievement and also the model for any science, in general. Pythagoras (580-500 BC) proved the existence of irrationals – and showed that the earth is round. Archimedes' law of buoyancy and his mechanics stand unchanged to this day, etc. The global view of the earth was pursued much further, as we shall see in the context of this chapter..

Erathostenes (256-196 BC) of Cyrena (in present Lybia), working at the scientific "academy" in Alexandria, {\it measured the radius of the Earth, with a better than one-percent precision!}
He had learned and checked that on a certain day in the year, the Sun was at its zenith in Syena (present Aswan), in upper Egypt. Holding a vertical pipe, he had checked that there was no shadow within the pipe. He arranged to measure on that same day the Sun's angle of elevation – in Alexandria. With this angle, and the precise distance between Alexandria and Syena, he could evaluate the earth's radius directly (see sketch). The precision mostly depended on the figure used for the Syena-Alexandria distance.
With Egypt already forming one relatively well-organized kingdom for two-and-a-half or three millennia, the precision had to be good – the Pharaoh's messengers had crisscrossed the land so many times that travel times were well-known and one also knew the figures in going from times to distances.

About a hundred years later, the earth's radius was measured for the second time, by Poseidonius, head of the Academy in the island of Rhodes. He used the star Canopus, in the Southern sky, which has a very small elevation in Rhodes, which he verified – and then added to the input the elevation angle from Alexandria. To this he had to add a figure for the Alexandria-Rhodes distance, which he took from an evaluation by some sailors. This figure was incomparably less good than Erathostenes' Syena-Alexandria distance. As a matter of fact, the distance used by Poseidonius was about one half the correct figure for that distance. As a result, Poseidonius' measurement yields an earth with a radius which is one half of Erathostenes' and of the true radius. Unfortunately, Ptolemy, when editing his "Geography" (around 150 AD), chose to include Poseidonius' measurement and ignored Erathostenes'. Thus, when forteen centuries later, Columbus became interested, he was using Ptolemy's "Geography", with Poseidonius' wrong figure. For the proposal which he submitted to Queen Isabella, he used these wrong figures – they indeed made the route to India much shorter when going from Spain or Portugal westward – and thus justified the cost of the trip, whose purpose was defined as "finding a shorter route to India" – thus hopefully reducing by a half the price of spices. Moreover this "shorter route to India" meant that the trip would last three months, for which he could carry supplies in his ships. The queen
(or her ministers), however, sent the proposal to the University of Salamanca for expert evaluation. The scholars in Salamanca knew of both Erathostenes' and Poseidonius' measurements, and agreed with Erathostenes. During the Roman Empire – and again in the last three hundred years – the map of the Mediterranean had been redrawn, first by the Romans, then by the Venetians and the Genoans, with good precision, so that Poseidonius' evaluation was rejected. The Salamanca scholars therefore issued a very negative report. They claimed (1) that Columbus would never make it, since his supplies covered only three months and the trip would last six months; (2) it would never pay to go to India through
the West, since this is a much longer route. Note that in the relatively recent (1992) film "Columbus", in which this role is played by Gerard Depardieu, the Salamanca professors are unjustly ridiculed, being made to claim that the earth is flat, with only Columbus insisting that it is round…

Clearly, the Salamanca report was correct – to this day, nobody ever uses the western route to India, for precisely the reasons quoted by the Salamanca professors.. And yet – what is the lesson with respect to scientific research and discovery? Again, the proposal should not be evaluated according to its claims with respect to "relevance" – here the expected financial gains. It should (and may indeed) have been judged from the point of view of exploration: it should have been intolerable that in 1492 nothing was known about the extent of the Atlantic Ocean, whether or not this was the same Ocean licking the shores of China and Japan, etc. Viewed as {\it exploration}, it was highly justifiable – and paid off indeed – but this was not the aim which prompted the kingdom to allocate the three ships...In Part IV of this book, we study the research process and in particular the manner in which random elements enter in an {\it evolutionary} view of Epistemology.

As is well known, there hsd also been an intentional research program that had discovered the American continent around 1000 AD, that of the Vikings. They were fine sailors but were forced to sail along the coastlines in order not to get lost. Iceland had been reached much earlier, but Eric the Red discovered Greenland around 970 AD and (his son) Leif Ericson reached "Vineland" (Labrador) in 1000 AD. The names were selected in an aggressive attempt to attract settlers (there was nothing "green" in Greenland and no grapevine could grow in Labrador) but very few followed and the program soon reached a dead end, mostly because it was tied to these glacial coastlines.

The situation changed in the Fourteenth Century with the arrival of the *magnetic compass* from China. This was a (positive) *active* mutation in the *technological environment,* also a *passive* mutation for the Spanish *exploration program*, for the states of Castille and Aragon, whose sailors could now dare set out on an exploratory trip without having to stick to the coastlines, and it triggered the Age of Discovery. This would be a complete description in the case of Vasco de Gamma or Magellan, but in Columbus' case there was in addition the erroneous theory about the size of the earth and the distance to India. Here *it is the theoretical* "*environment*" *which was wrong* and he selected the wrong route to go to India. That he reached America instead of India is a type M (serendipity) mutation. Three mutations brought about the discovery, one in the technological status of that Society, a positive *passive* mutation; another in the evolution of *geography*, an epistemological type E mutation, and lastly "going to A and reaching B" an ordinary serendipitous discovery. In the type E case, America is the *scalawag* beneficiary.

It is thus a scientific and/or technological advance which starts the evolutionary drive in Society. Presently, this is also the role played by Scientific Research. Let us study several other examples – the first of which is connected to our last one through a poetic thread…

{\bf 5.4 Another Italian Navigator: the Discovery of Nuclear Fission}

When Enrico Fermi (1901 - 1954) managed in 1942 to activate for the first time an experimental nuclear 'pile' at the University of Chicago – and thereby validate the ideas about the role of the neutrons in generating a {\it chain reaction}, a pre-arranged concealed report to Washington was sent as a telegram "The Italian Navigator has arrived in the New World". Let us stress that in those days, the relevant researchers did believe that the impact of this Second Arrival would compare favorably with that of the first.. Moreover – and this was certainly not the intention -- Enrico Fermi, the "navigator", like his Genovese predecessor, {\it only made it as a result of an error.}. After Sir James Chadwick's (1891 - 1974) 1932 discovery of the neutron and the exploitation of neutron beams by the Joliot-Curie couple (Frederic 1900 - 1958, Irene 1897 - 1956) in producing new isotopes of known chemical elements (this was described as the discovery of "artificial radioactivity"), Enrico Fermi and his group in Rome "joined the party". Fermi used the neutrons to bombard Uranium, element number Z=92, which had de-facto closed the Periodic Table since the eighteen-seventies – in the hope of producing "trans-uranic elements" (this was here the equivalent of the "India of the spices", in Columbus' thinking). In 1938, Fermi indeed thought he had produced new chemical elements – "pseudo-barium", "pseudo-iodine", etc.. and announced his discovery of elements 93 and 94, an announcement which was soon followed by the Nobel Committee's decision to grant Fermi the 1938 Nobel Prize in physics "for his discovery of elements 93 and 94." Yet another public announcement, which was published around the same days, was Mussolini's decree – surrendering to Hitler's pressure – instituting the Race Laws in Italy. Fermi had a Jewish wife and children which would now also count as Jews, and (justifiably) worried about his family's future. The solution he found was to take the whole family to the Nobel ceremony at Stockholm and make arrangements to proceed from there directly to the USA. The scheme worked out perfectly, with the exception of Laura Fermi's father, an Admiral in the Italian Navy, who felt he could not flee his motherland, returned to Italy after the Stockholm ceremony – and died in the Holocost with six million other Jews.

Another lady of Jewish origin (she converted to Christianity at 30, but this had no practical effect as far as the Race Laws were concerned) was the physicist Lise Meitner (1878-1968), well-known as the partner and collaborator of the German chemist Otto Hahn (1879-1968). The Hahn-Meitner collaboration had made important contributions to Nuclear Science, but Meitner had recently been forced by the Race Laws to flee Germany and was now a refugee in Sweden. On Christmas 1939, she was visited by her nephew, the physicist Otto Frisch (1904-1979) who describes himself in his autobiography "The Little I Remember" as "the physicist who had an aunt in every port".. Frisch who had also had to flee Germany was now a fellow at Niels Bohr's Institute in Copenhagen. Being thus in the vicinity, he had also visited his aunt.

Lise Meitner had just received a letter from Hahn, reporting on his having repeated the Fermi experiments, checking on the supposed production of elements 93 and 94. Hahn was an excellent chemist, as Meitner knew well; he was now assuring her that "pseudo-barium" was just actual barium, while "pseudo-iodine" was simply iodine. Hahn was willing to swear to attest these facts. Meitner knew how reliable Hahn was – and yet how could barium and iodine have appeared in this context? Walking and talking, Meitner and Frisch suddenly got it: this was just {\it nuclear fission}, the uranium nucleus splitting in two. Barium and iodine have nuclei with A values of about one half of that of uranium. Gradually, fission became more concrete and more familiar. Returning the next day to Copenhagen, Frisch enlightened Niels Bohr, who was leaving the next day for a conference in the USA. Bohr brought the news to New York, where John Wheeler carried them to Fermi and to the Hungarian group – Szilard, Wigner and Teller. Returning to the earler stages in 1939, both "Italian navigators" had set themselves erroneous aims – the road to India in 1492 and elements 93 and 94 in 1939 – and did not discover the truth about their findings until much later and only after the intervention of others.. It is interesting that Emilio Segre – also a first class chemist and the discoverer of the elements technetium and astatine – did not reach at the time Hahn's strongly critical conclusions. Was it a matter of experience, equipment or of Fermi's enthusiasm?

{\bf 5.5 A different Role for Randomness: the Laser and its Applications}

Randomness has different ways of entering the scene and influencing the evolution of society. Let us take an example in which the scientific discovery was entirely disconnected from its applications. The
{\it laser} was discovered by Charles Townes (b. 1915) and others in the fifties, following Albert Einstein's 1905 and especially his 1917 paper on the quantum behavior of light (photons). When Townes and the others had achieved "lasing", they had as yet no idea what it would serve for. Nowadays, we prefer the precision of musical reproduction as achieved in a {\it compact disk}, with a laser reading the engraved recording. This book, presumably, was printed with a laser-printer; my suit was cut by laser, the various Air Forces use "clever" bombs – where "clever" indicates the action of a laser-guide; the earth-moon distance is now known to within a centimeter, thanks to a laser whose beam hits a mirror which was set up on the moon by the 1969 astronauts – and the Strategic Defense Initiative included the use of powerful lasers of various types for the destruction of rockets. Clearly, there was no initial research proposal listing as the aims "development of a musical instrument with the purest timbre" or "development of instrumentation for the cutting of suits".

GPS

{\bf 5.6 "Relevance" and "Applicability" are irrelevant}.

In 1977, while I was on a one year visit at the Institute for Advanced Study at Princeton, I was invited by Caltech to partake in a conference on {\it Relevance} sponsored by the Fairchild Foundation. Since 1965, "Relevance" had become an often cited criterion in analyzing scientific programs, in the discussions about the funding of research In the communist countries -- and sometime in the USA -- there had generally been a pragmatic priority for {\it applied} research, as against {\it pure} science. In 1965, the discussion was reopened in the USA by Alvin Weinberg, the physicist and influential director of the AEC's Oak Ridge National Laboratory in Tennessee, aided by his physicist colleague Eugene Guth. The latter had studied a famous speech made by the great German mathematician David Hilbert (1862-1943) at the turn of the century. Hilbert was presenting his views with respect to the assignment of priorities to topics and areas in Mathematics. Rather than taking the naïve and common position requiring the researcher to point to
some expected applications justifying the choice of problem, Hilbert's approach was more abstract and taking into account the possibility of unexpected bonuses developing in related fields. To include these indirect possibilities, Hilbert based his approach on a probabilistic analysis, like a lottery, or stock exchange considerations. His suggestion was to prioritize those areas which had strong interconnections with other areas, i.e.

which were {\it relevant} to other areas. As one could never know a priori what the outcome might be, one was thereby maximizing the prospects -- even some inessential discovery in field X might still prove to be very important in one of the fields A, B, C, related to X. Alvin Wenberg generalized the approach to science and technology in general. I remember, on a visit to Oak Ridge, having to defend Elementary Particle Physics, which was being -- rightly or wrongly, depending on whether we use foresight or hindsight -- characterized as having almost no connection with any other field, due to its "narrow front" and deep penetration policy.. I appreciated Hilbert's probabilistic argument, but was unconvinced as to its applicability as even the connections to another field might not be known prior to the results of the new research. We have since observed the effect in Particle Physics, which in its theory part suddenly in the nineteen-eighties gave birth, not only to an entirely new domain in Cosmology (the Inflationary Model) but also to a new science, admittedly somewhat esoterical, bamely Cosmogony, the science of the creation of universes – while its experimental component produced the least esoterical product, name;y the internet.

What then is the overall lesson – to be assimilated by governments, foundations or research directors? It is known that some Communist regimes tried several times to push their researchers into channels which could be justified by the ideology. This happened in the USSR, in China and in some Institutes in the West in which the general atmosphere and the political stand of the scientists themselves were sympathetic to Marxism: in Paris at the Institut Henri Poincar{\'e} in the Fifties, in Japan at Nagoya University in the Fifties and Sixties, etc... The ideological interventions varied in intensity, from the most simple-minded ("a researcher who worries about the interests of the worker should restrict himself to {\it useful} topics" to the very refined, such as the selection of highly mechanistic models when working out the kinematics of elementary particles – with ever-recurring references to Lenin and to the great victory of Marxism or of Dialectical Materialism over "Mach, Ostwald and the Positivists" when it was shown that {\it atoms really exist} and are not just abstract conceptual models, as claimed by the latter. I have written about this aspect elsewhere, in {\it Interaction between Science and Philosophy} (Samboursky 1971 Jerusalem Symposium), Y. Elkana ed., (Humanities Press, Atlantic Heights, 1974) p.1-26 and with a Japanese version in {\it Shizen 71-12} (1971) 94-105.

The result was sometime a deterioration or decay in the quality of the research – as happened with the biologists in Russia under Lysenko or to the geophysicists under Belyoussef. In other cases, research went on almost undisturbed – under the cover and protection of words. One such shield consisted in quoting Lenin on the future discovery of further structure in the electron. An alternative defense sometime used consisted in attacks on colleagues in the West. The theoretical physicist Fock (Vladimir A. Fock, 1898 - 1990) wrote a textbook in General Relativity and explained in his introduction that the theory is good, even though Einstein had given it originally an abstract and worker-negative twist, but he, Fock was now redirecting it in an ideologically healthy direction. In another book, Fock criticizes Bohr for having given Quantum Theory an idealistic flavor, which he, Fock, is now removing and replacing by healthy materialism…In China, the situation was at its worst during the "Cultural Revolution"..

Unfortunately, however, these difficulties have not been limited to Communist countries. In the West, there is, over the years, a recurrent interest in {\it "relevance"}, supported by a few "overconscientious" scientists. Much of the research expenditure is paid for by public funding - and the scientists would like to feel that they act according to the interests and wishes of the taxpayer – by working on {\it relevant} topics.. One such "wave" passed over the USA in 1965. The movement was initiated and led by the physicist Alvin Weinberg, Director of the Oak Ridge National Laboratory (of the Department of Energy), assisted by his physicist colleague Eugene Guth, of the same institution. The two had been searching for objective criteria by which to evaluate {\it relevance}. Guth indeed discovered such a method, in a 1900 lecture by the great German mathematician David Hilbert (1862-1943), speaking to the German Mathematical Society. Hilbert's idea was {\it to prioritize areas in mathematics which had multiple connections with other areas}. Analyzing the various chapters of mathematics (or topics) which appeared intrinsically interesting, he added a rubric in which he listed connections with (or to) other chapters, other topics. The rationale was that by prioritizing such connections-rich topics, there would be a higher probability that the support provided to a given area would end up being useful for something, even if the area itself proved to be a dead end. Visiting Oak Ridge and lecturing on SU(3), I was challenged to display connections between Particle Physics and any other areas. They were not many, at that time – the intriguing relationship with Cosmogony had not yet been realized. Nuclear Physics was almost the only recognized link and I felt as if I belonged in an orphanage.. Particle physics is an expensive discipline, depending as it does on high-energy accelerators, and Alvin Weinberg's main conclusion from this excursion into a new methodology was that this money was wasted – in the light of the great Hilbert's method of evaluating relevance – which now meant "relevance to other areas".. I appreciated Hilbert's probabilistic argument, but was unconvinced as to its applicability as even the connections to another field might not be known prior to the results of the new research. We have since indeed observed the effect in Particle Physics, which in its theory part suddenly in the nineteen-eighties gave birth, not only to an entirely new domain in Cosmology (the Inflationary Model) but also to a new science, admittedly somewhat esoterical, namely Cosmogony, the science of the creation of universes – while its experimental component produced the least esoterical of products, namely the internet. So much for predictability of the unpredictable…

I have studied an example which was topical around the beginning of the Century, would have come out extremely low on connections to other areas – i.e. on Hilbert's relevance scale – and yet has proved to represent the most important research result we have passed on to the next Millenium! This is the emergence of the modern computer, as a result of the redevelopment of mathematical logic – after the confusion created by the 1905 Russell-Whitehead paradox. I shall tell that story in the sequel, but note here that the Hilbert/Guth/Weinberg objective relevance criteria were very inadequate..

At about the same period of the late Sixties, the American legislature started working on what ended up as the "Mansfield Amendment". This forbade the Defense services from spending any funds on research which is not directly and obviously defense-related. Historically, much good science was initiated by the Office of Naval Research, for instance. Michelson, for one, was for many years on the staff at Annapolis and while there, advanced extensively our knowledge of topics relating to the velocity of light. The US Air Force gave research contracts in basic science, including to the best non-American scientists; as a result it had the possibility of addressing questions at all times to the best scientists. The Office of Aerospace Research had first class contacts and could consult the best consultants. After the Mansfield amendment, they were only allowed to study the purely military issues, and could not explore new (not-yet-obviously military) problems. This was not directly related to the "relevance" issue, but was certainly partly inspired by it – though much motivation might have had its origins in post Vietnam anti-defense feelings.

In a somewhat similar anti-research spirit, the American Senator William Proxmire invented a yearly "prize" ("the Golden Fleece") which he "awarded" to the research project which appeared to him to represent the least relevant and most preposterous research project in the year's program.. One wonders what would have been Proxmire's reaction, had he been aware of the fact that the articles which helped Charles Huggins receive the 1966 Nobel Prize in Medicine (for the development of methods of handling human prostate cancer) included research performed by the Scottish physician John Hunter (XVIIIth century) on {\it the prostates of bulls} and by the English physician Griphiths (XIXth century) {\it on the prostates of hedgehogs and moles}. These studies certainly belonged to the class which was guaranteed to be awarded the Golden Fleece by Proxmire, and to be strongly ridiculed ..

In the USA of the Nineties, there is a renewal of such pressures. After the collapse of the USSR and the end of the Cold War, neither senators nor congressmen have any fear of causing some delays in the development or adoption of any new technology, be it important to defense considerations, as a result of their disregard of some project in basic science. Under present conditions, priority is granted to projects of immediate importance – or such as would be important for the special interests of their constituencies. One such development has been the closure of the SSC in Dallas, even after an expenditure of 2.5 billion dollars.

Should I be asked how can one nevertheless make a selection and decide which proposals should be supported, my advice would be (a) not to judge by the scientist's own justification – he himself might not know what to expect as the real outcome. His presentation should be used as a means of reaching a personal evaluation of the scientist. (b) I would look seriously at the researcher's previous work. Essentially, I would try to find out whether in the conditions which faced Sir Alexander Fleming, this researcher would have realized the value of the dead bacteria and identified the agent which caused their death –as Fleming did – or whether, instead, he would have concluded that he should better be more careful next time and remember to tighten that lid..

{\bf 5.7 A Sophism Gives Birth to the Modern Computer}

The example we bring now can be appreciated without studying the mathematical details – and readers who have no empathy for the aesthetics of mathematics may skip the next two pages and rejoin us when we arrive at the Russell – Whitehead paradox. Here, however, is the full story.

In the beginning of the XXth Century, a serious crisis developed in mathematical logic. It had the dimensions of a true "scandal" in mathematics. For some twenty years, the field had grown nicely, as a result of the merger of two disciplines, two new initiatives – Set Theory on the one hand and Symbolic Logic on the other. Set Theory was invented by Cantor (Georg Ferdinand L.P. Cantor, 1845-1918) one of the most original thinkers in the history of mathematics. It is both instructive and touching to read about him in one of the biographical chapters of E.T. Bell's {\it "Men of Mathematics"}. The first edition (1937) contains remarks typical of academic America in the Thirties – discussing Cantor's Jewish background, his encounter in Berlin with another Jewish mathematician, Leopold Kronecker – followed
against by the remark: "The aggressive clannishness of Jews has often been remarked, sometimes as an argument employing them in academic work, but it has not been as generally observed that there is no more vicious academic hatred than that of one Jew for another, when they disagree on purely scientific matters.". Bell (a professor of mathematics at Caltech) goes on to describe such a quarrel, first in general and then in the Cantor – Kronecker case, with Cantor ending up in an asylum..It is instructive that in the second edition of Bell's excellent book – issued in the Sixties – this entire piece is missing – it was no more {\it politically correct}. It is also interesting to note that very similar comments about not appointing Jews in academia because "they do not know how to behave" were recently found in the reports of the appointments committee studying the case of Albert Einstein's candidacy for a professorship in Zurich in 1911 – and in that of the Princeton University 1949 graduate school committee, dealing with the admission of Richard Feynman. In both cases, the committee assures the university that this candidate is not like "other Jews". He will behave properly..

Cantor succeeded in turning Set Theory into a powerful tool for the classification of infinities and for the creation of a {\it calculus} of infinities. At the foundations, he set {\it countable} infinity (the set which can be put in one-to-one correspondence with the sequence of integers 1,2,3,…). This set he named {\it aleph-zero}, using the Hebrew letter of that name $\aleph_{0}$, from the Hebrew word for {\it infinity} אין-סוף ({\it ein-sof} i.e. no end), written with an {\it aleph}. The {\it zero} index indicates that this is the smallest infinity as a cardinal and the first as an ordinal. Between two sets A,B, one uses as a definition for $A>B$ the method of putting the elements of the two sets in one-to-one correspondence; the relation then implies that there will be at least one element of A which will have no "partner" in B.

Using plain combinatorics, one proves a theorem stating that for a set with n elements, the number of subsets is 2^{n}, Including the empty set and the full n-element set. Taking just the one-element subsets, there are n of them, and they can be put in one-to-one correspondence with the original set. It is therefore clear that the number of subsets will always be larger than the cardinal describing the original set, namely that $2^{n}>n$ Cantor applied this construction to define ever-larger infinite cardinals, starting with

$$
\aleph_{1} = 2^{\aleph_{0}}
$$

and so forth, i.e. $ℵ _{n+1}= 2^{ℵ_{n}}$. Cantor proved that the number of {\it even} or of {\it odd} integers is also $ ℵ_{0} $, since the elements $2m$ of the {\it even} subset can be put in one to one correspondence with m in the plain sequence of the countable infinity, i.e. they are {\it countable}:
.
$$
2 & 4 & 6 & 8 & 10 & 12 & 14 & … [the even integers].
1 & 2 & 3 & 4 & 5 & 6 & 7 &…. ["counting" them]
$$

The same "counting" can be done for the set of {\it odd} integers. Clearly, infinite sets have their oddities: a set can be equal to some of its subsets! Cantor also proved that the number of {\it rational numbers} is also $ ℵ _{0}$. Rational numbers are those numbers which can be written as quotients in dividing two integers, namely the {\it fractions}, $f = p/q$ with integers as p and q By including "fractions" with unit denominator $q=1$ i.e. the integers, we see that "rationals", in ordinary parlance, is synonymous to "integers and fractions"

To see that the rationals can indeed be counted, we organize integers and fractions according to the sequence

$$
1/1
|
½,-- 2/2
/
1/3 -- 2/3 -- 3/3
/
/
/
/
¼ --- 2/4---¾ ---4/4
/
/
/
/
/
1/5---2/5---3/5 ---4/5---5/5
/
/ …and so forth
$$

which makes it clear that {\it the rationals are countable}, i.e. they form a set of cardinality $ ℵ_{0}$). Not so the {\it irrationals}, as proven in Cantor's famous {\it diagonal proof}. But first let us remind the non-mathematically inclined reader of the nature of the irrationals, i.e. those numbers (such as π or $\sqrt{2}$) which (we claim) cannot be written as a quotient of two integers, or $z \neq p/q$.
Perhaps we should also refresh the reader's memory with respect to these {\it irrational numbers}. That such numbers exist was first proven, to our knowledge, by Pythagoras (or by some of his disciples), in "Greater Greece" (southern Italy) in the sixth century BC. First, they constructed a right angle isosceles triangle whose orthogonal sides are equal and of unit length. Then, since the area of each of the two squares built on these sides will be $(1)^{2}=1$, the area of the square built on the hypotenuse (the side opposite the right-angle) will be, by Pythagoras' famous theorem, $1 +1=2$. Thus, the length of that hypotenuse is $\sqrt{2}$. They therefore studied the nature of this number, representing the length of an object which exists both in practice and in the abstract and checked whether or not it could be written as a fraction. Note that this includes the possibility of writing it in our presently popular decimal system with a finite number of digits after the period sign, as, for example by writing $11/10$ for 1.1, or $2,856,321/10,000$ for 285.6321, etc. The Pythagoreans then discovered that the $\sqrt{2}$ cannot be obtained by dividing two integers. i.e. $\sqrt{2} \neq p/q$. The proof is easy to follow: squaring both sides we get $2=({p}^{2})/({q}^{2})$ or, in other words,

$$
p^{2} = 2 q^{2}
$$

an equation which we denote by X.

This result X, said the Pythagoreans, cannot be true! Suppose we decompose p or q into prime factors – for instance, if $p=2,904$, it will be written as ${2}^{3}\times 3\times {11}^{2}$, etc. Each of the two integers p and q is either odd and does not contain the prime number 2 in its decomposition into prime factors – or is even and contains some finite power of 2; in either case, however, the squares p^{2} and q^{2} each contain an even power of the factor 2, since they result from a self-multiplication, $p^{2}=p\times p$. For the value we took as an example, $p=2,904$, the factor 2 appeared as $2^(3)=8$, and p^{2} will contain in its factorization into primes a factor 2^{6}, i.e. an even power (6, here). More generally, if p contains 2^{n}, n some positive integer, then p^{2} will contain precisely 2^{2n}, etc. With this result, we get a {\bf paradox} in equation X, since the left-hand side contains an even (or zero) power of 2, whereas the right-hand-side has an additional factor 2, on top of the even power of 2 in q^{2}, i.e. {\it an odd power of 2}.
Clearly, what was wrong here was our very assumption that $\sqrt{2}$ can be written as p/q.

Thus, there are numbers which cannot be expressed as quotients between two integers. In the decimal system an irrational will thus have an infinite number of digits past the decimal dot; note, however, that not all infinite-digit numbers in the decimal representation are irrational: for instance, $0.333….= 1/3$, i.e. $p=1$, $q=3$ and is thus a rational fraction.

We now arrive at Cantor's {\it "diagonal" proof}. It demonstrates that {\it the number (or the cardinality) of the irrationals is larger than $א _{0} $, i.e. it is uncountable}. Cantor first tried the assumption that they can indeed be counted. He assumed he was counting the irrationals and rationals together, in a stretch of the continuum between $N=0$ and $N=1$.. Counting a set requires arranging its elements in a one-dimensional sequence Suppose we have managed to find a linear sequencing and that I am now counting the elements. A piece somewhere along the sequence will have the form,

```
$$

::::::

0.   a_{1}   b_{1}   c_{1}   d_{1}……
          \\
            \\
              \\
0.   a_{2}   b_{2}   c_{2}   d_{2}
                       \\
                         \\
                           \\
0.   a_{3} b_{3}  c_{3}  d_{3)..
                                      \\
                                        \\
                                          \\
0.  a_{4} b_{4}   c_{4}   d_{4}..
                                                  \\
etc.(an infinite sequence)..
```

The letters a_{n} etc., represent some digit. Cantor now drew a diagonal along the whole list and suggested writing down a new and different number,

$ 0. \not {{a}_{1}} \not{{b}_{2}} \not{{c}_{3}} \not{{d}_{4}} ..$

where the first digit could be {\it anything except for} a_{1}, the second is again allowed to take {\it any value, except for} b_{2}, the third will take any value, except for c_{3}, the fourth will take any value except for d_{4}, etc.. Thus, {\it the new number differs by construction from all numbers in our ordered list} – and yet {\it it is one more number between 0 and 1 and should therefore have appeared in that list!}. This proves that there is no such ordered list, and thus {\it there is no way of counting these numbers.}, which can be written as (${\cal C}$ is the {\it continuum}).

${\cal C}> ℵ_{0}$

The continuum includes all rationals plus all irrationals, and as we have proved that the rationals are countable, we can blame the uncountability on the irrational numbers. Our result regarding the continuum also begs the question – is ${\cal C} = ℵ _{1} $? - a question which was indeed open till 1964, when Paul Cohen of Stanford answered it by proving that this issue is open and that one has to add a separate axiom to provide the answer. This new axiom may be chosen in various ways – which would also fix the value of ${\cal C}$. In several examples, it might range from somewhere between $\aleph-zero$ and $\aleph-one$ to equality with $\aleph-one$ or with some higher cardinal.

So much for the achievements of Set Theory and its conquest of the infinites. At the same time, another mathematical discipline, symbolic logic, had also energized Mathematical Philosophy. George Boole (1864-1915) and Gottleb Frege (1848-1925) invented Symbolic Logic - though some basic concepts were already suggested by Gottfried. Leibniz (1646-1716) . Together, Cantor's Set theory and the Boole-Frege Symbolic Logic, gradually merging, were adding new and apparently very sharp combined tools for the abstract treatment of mathematics and the mathematical logician Bertrand Russell (1872-1970), together with the mathematical physicist Alfred Whitehead (1861-1947) set out to reconstruct the whole of Mathematics out of a set of axioms, in the spirit of Euclid's Geometry. The aim was to identify the precise set of axioms thus making up the Foundations of Mathematics. Russell's project was also related to one of the problems listed by David Hilbert in his 1900 talk, the so-called "principal problem of mathematical logic". The idea is to prove or disprove the possibility of finding an algorithm which would enable one to know whether or not a given proposition would be true, within a given set of defining axioms. It was while investigating these foundations that Russell and Whitehead encountered the paradox. A question arose - does the set of all sets which do not contain themselves contain itself? If it does, then it cannot belong there – and if it does not, then it fits the category and it does..

For our non-mathematically-minded readers, here is a faithful analogy: think of a town in which a contract has been signed by the municipality with a barber, according to which he is supposed to shave all males which do not shave themselves. Question: should he shave himself? If he does, then he does not belong to the category which he is supposed to shave according to the contract; but if he does not, he becomes precisely a member of the category he is supposed to shave. What should he then do?

The news about the paradox brought about a universal burst of laughter, much of it at the expense of the departments of Logic everywhere, whatever their appartenance - whether to Philosophy or to Mathematics. The great French mathematician Henri J. Poincar{\'e} (1854-1912) qualified Cantor's theory of Infinite Sets as "Jewish Mathematics", by which he meant (it is claimed) to compare it to {\it pilpul}, the sometimes hair-splitting (in the eyes of outsiders) logical inference mechanism in talmudic hermeneutics - while also pointing to Cantor's origins. Cantor himself could not react - he had already been partially hospitalized in an asylum since 1899 and was outside of the intellectual circuit anyhow. Even Hilbert, who in his famous 1,900 address to the German Mathematical Society had included (as described above) the construction of the foundations of mathematics in his list of "important mathematical problems", now kept away from this issue, which could not pass the "relevance" test either. .

After a while, the stunned logicians initiated a remedial program. In 1908, Ernst Zermelo (1871-1953) set out on a reformulation of the axioms, building carefully, from the bottom upwards. All the time, he and others kept an eye on possible paradoxes and how to bar them from entering the system. The reconstruction program achieved a first draft of a "tight" set of axioms, known as the Zermelo-Fraenkel axioms. Abraham A. Halevi Fraenkel (1891-1965) -- somewhat later (1925) the founder of the department of Mathematics at Hebrew University (Jerusalem) -- and the Norwegian logician Thoralf A. Skolem (1887-1963) completed the axiomatic foundations The list was now made up of ten axioms, plus some open questions which were reformulated in a "sharper" presentation. One of these was the necessity for an {\it axiom of choice}, in constructing Cantor's {\it diagonal} proof -- and the related question of the relative position of the continuum ${\cal C}$ among the sequence of {\it alephs}. As we mentioned, these questions were answered in the fall of 1964, after Fraenkel had recapitulated the program in a colloquium lecture at Stanford Unviversity. Paul Cohen, a mathematician sitting in the audience went home and solved the problem completely, so that when Fraenkel died in 1965, he al least had the satisfaction of having brought about the closure of the entire issue.

Returning to 1922, we observe the (only partially-finished) program being picked up by logicians everywhere for further elaboration. In 1928, Hilbert restates his quest in a little book with Wilhelm Ackermann "Grundzuege der Theoretischen Logik" emphasizing the basic concepts (such as {\it and, or, not, if, .., there exists, etc}.In 1930 Budapest, a doctoral thesis - that of John von Neumann (1903-1957), considered as one of the most brilliant minds of the century${{}^{*}\footnote}{*{Von Neumann is one of the so-called "Martians", namely five Hungarian-Jewish scientists who fled Europe after the Nazi's rise to power in Germany, "revolutionized" the American scene and had a tremendous world-impact: Theodore von Karman (1861-1963) – of jet flight fame , Leo Szilard (1898-1964) co-inventor of molecular biology, Eugene Wigner (1902-1995) nuclear physicist, Edward Teller (b. 1908) physical chemist and co-inventor of the H-bomb and J. Von Neumann. See {\it The Voice of the Martians} by George Marx, pub. by Akademiai Kiado, Budapest (1994)}} - adds to the completeness of the set of axioms, especially after P. Bernays (1888-1970) had shown how to incorporate this contribution. A further modification is introduced in 1940 by the great Austrian-Czech logcciian Kurt Goedel (1906-1978), thus completing the transformation of the "Zermelo-Fraenkel axioms" into the "axioms of von Neumann, Bernays and Goedel".. When restricted to {\it sets}, the new axioms are identical with the original array; however, the new formulation covers much more than sets, it holds for more general logical constructs. Moreover, the remaining open questions, as listed by Zermelo-Fraenkel, have since been reset in a more open formulation, especially after applying Goedel's undecidability theorem. The more general implication of this theorem consists in the {\it undecidability of Arithmetic}, namely that there will always remain statements which cannot be proven right - or wrong - but neither can the opposite statements be either proven or disproven. Constructively, this also means that either one of the opposing statements could be added as a new axiom and that one could thus develop various branches of mathematics which differ in the fundamental axioms.

In his proof, Goedel used a concept of {\it constructable functions}or, equivalently, {\it computable numbers} - and in 1936 he further improved the definition - and yet there were still some lingering doubts about the precision of this definition A graduate student in Cambridge (England), Alan Mathuson Turing (1912-1954) was given for his Ph. D. thesis the problem of further improving on that definition He transferred to Princeton in 1936-1938, working on this problem, with Alonzo Church as thesis advisor and publishing in 1937 "one of the most significant mathematical papers of the century", {\it On Computable Numbers}.

Turing thus responded to the challenge with a beautiful idea, that of a {\it Turing machine}.It is fed by an infinite tape, which is divided into square cells, with a digit in each cell: in a binary base, these would just be either {\it ones} or {\it zeros}, but any other base would also do. An empty cell is the same as a cell with a zero. The number of cells carrying {\it ones} (in the binary case) or any non-zero digit has to be finite, even though the tape is infinite. The tape is fed one-step at a time, with three allowed "motions", namely one step to the right ("R"), one step to the left ("L") or just staying
in place or stop ("S"). The machine has a {\it scanning head "H"}which reads the tape cell by cell. It carries a {\it program "P"} written in {\it 5-word sentences}.The first "word" describes the machine's initial state ("Si"), The second "word" selects one possible digit which might appear (inscribed) in the tape's cell now entering the Head; it should be read as "if the digit on the entering cell on the tape is "t", then..".The third "word" is an instruction "X" to {\it replace the digit "t" by a (generally different) digit "x"}, (either "x= 0" or "x" might be any of the digits making up - together with "0" - the base used). Should "X" be a zero, the action would represent a deletion of the figure "t" in the current cell on the tape. The fourth "word" is an instruction fixing the motion of the tape - namely either "R" or "L" or also "S" (stop).The fifth "word" describes the machine's final state ("Sf"). Note that the first two words together describe initial conditions, the last three describe the resultsof the Head's action, given these initial conditions. For one set (Si, t) one can have only one continuation (I, X, Sf), otherwise the program would be non-deterministic.Moreover, should there be no instructions in P for a particular pair of initial conditions, the machine will stop, as if the fourth word was "S".

To acquire some notion of how a computation is performed by the Turing machine, let us take the simplest example. To have a number n as input, we inscribe a series of $n+1$ digits "1" on our tape. To multiply this n by 2, the program P will have a 4-word sentence which will cause the Head to skip the first "1" and copy the rest into the squares following the last "1". As a result, we now have $2n+1$ digits "1" - which is the notation for the number $2n$ (the Head can also have this result printed out as $2 \times n = 2n$).

With this set-up, the {\it Turing machine} can perform all imaginable calculations, i.e. it does solve Turing's doctoral research problem: a {\it constructable function} is one which can be evaluated with a Turing machine, indeed - this is a very concrete definition and it adds to the strength of Goedel's theorem of undecidability Moreover, the Turing machine can thus really replace the human brain in a variety of cases - not just computations, as was subsequently proved by Alonzo Church. Applying Goedel's method, Church showed that any {\it logical statement (of the type "A is B", etc) can be faithfully represented by an arithmetical relation involving numerical digits}, which can then be treated on a Turing machine. As a matter of fact, {\it almost all our present computers are algorithmic, and all algorithmic computers are Turing machines}, as we shall see in the sequel. Note however, that as late as 1956, one of the experts on computing, Howard Aiken, still stated that "the most amazing coincidence" would be required for a {\it computing machine} to be able to perform anything beyond actual calculation - such as to control sales in a store, or to handle flight reservations...

At this point we terminate our excursion into Set Theory and Mathematical Logic and return to general world history. By the time Turing had returned to England and finished his thesis, the Second World War was raging throughout Europe. The British High-Command was well aware of the importance of Intelligence at all levels, and Alan Turing was mobilized and sent to the Blechley Park {\it Code and Cipher School}, an Intelligence base where most of the cryptographical work was done. Some of the most talented students in mathematics at Cambridge and elsewhere were brought over to this base and given cryptographical tasks. The most important project concerned the German
diplomatic and military code {\it Enigma}. The Germans were using an {\it Enigma machine} for the encoding, a typewriter-like machine - except that its printed output would be encoded by three or four rotors which changed position after each letter. With some further complications, this was equivalent to a periodicity of over a trillion in the polyalphabetic system - and the German command felt very safe with this code. To decipher such a code, one had to guess and check one's reading by heavy combinatorial
computing. The Polish forces had already built a set of primitive calculating machines, known as the {\it Bombes}. At Turing's suggestion, a 'Turing machine' was built (named
{\it The Collossus}), performing all the heavy calculations. "Enigma" was indeed successfully deciphered and this was extremely important in winning the war. Alan Turing is perhaps the one single person who contributed more than anyone else to that victory. At the same time, the Collossus was the first modern computer, in hardware too, as it had 1500 vacuum tubes and the engineers at first did not believe that at any moment
there would always be a deficient one…

Once the War ended, Turing went on to design a new computer, {\it ACE
("Automatic Computing Engine")} at the National Physical Laboratory and in 1948 he moved to Manchester University, where he built {\it MADAM (Manchester Automatic Digital Machine)} He committed suicide in 1954, following a trial for "gross indecency" (he was an homosexual). Aside from contributing so much to the victory over Nazi Germany, he had also launched the Age of Information.

In the USA, it was another contributor to the Set Theory axioms, John Von Neumann, who - realizing in his wartime military contribution, a need for rapid computing
(non-combinatorial, in his case) - developed in 1945 at the Institute for Advanced Study at Princeton another version of the Turing machine, which he named a {\it Stored Program Computer}. Commercialization occurred in 1951, with the launching of
UNIVAC 1, a general-purpose, stored-program electronic digital computer.

Charles Babbadge (1792-1871) is generally credited with the invention of computers. A Cambridge professor, he managed to convince HM's government of the importance of his project, namely building a calculating engine in order to check the various mathematical tables, and did receive financial support for it. He initiated the construction of a single-task calculating machine (it was an analog mechanical computer, all gears) named {\it Difference Engine No. 1}, followed by an improved version (No. 2). Later on he even conceived the idea of a *program* and started work on its design - but he had meanwhile lost his governmental financial support and he never finished the programmable computer. Babbage is mainly remembered through the writings of his mistress, partner and chronicler, Ada, Countess Lovelace, Lord Byron's (the poet) daughter .

Summing up, after thousands of years of the {\it abacus} and beads, Blaise Pascal (1623-1662) and Gottfried Leibniz (1646-1716) built mechanical calculators (Pascal's could only add and subtract, Leibniz' could also multiply and divide) using pegged wheels. Jacquard's invention of the automatic weaving loom (1801) added this {\it punched cards} technique for programming. It was used (the Hollerith machine) for the 1890 census in the USA. Then came Babbadge - and yet nothing really got going - mechanical computers were terribly heavy and volume-consuming. Then, all of a sudden, in trying to overcome a philosophical paradox, the idea of the modern computer emerged; meanwhile electronics had become a science and the space age has since boosted miniaturization. The modern computer and the Age of Information have thereby dawned on us.
The Russell paradox was neither relevant in the Hilbert - Alvin Weinberg sense – nor was it useful or utilitarian - and yet it gave us the most important legacy we leave to the next Millenium!

{\bf From High-Energy Scattering to Surfing}

The Nineteen-Seventies have been witness to the victorious drive and complete takeover of Western Society by the Internet, resulting in a new strength, characteristic of a slightly improved collectivity and interdependence. The move started at CERN, the European high-energy accelerator center, as a drive aimed at improving everyday communication – within the center itself with its various machines and experimental teams. This included programs aimed at creating an interface between computers of different makes.

A second initiative started within the American Defence research personnel. These were interested in designing a communications' network internationally. One one-step result was the introduction of e-mail, which was meant to provide uninterrupted communication in an emergency, plus various services in everyday life. The two efforts merged in the Eighties and the Internet was born.

Part IV The Evolution of Scientific Ideas: Evolutionary Epistemology

Abstract

The evolution of ideas involves the same basic elements found in any evolutionary process, namely (a) an information-carrying control program undergoing a routine of manipulations, (b) which sometime induce the occurrence of errors in the transmission of that information, (c) and with the possibility that such an error might on rare occasions generate new useful instructions within the original program. XXth Century advances in the History and Philosophy of Science, as represented by the four conceptual contributions due to Popper, Kuhn, Lakatos and Feyeraband, fit very simply with the evolutionary mold, which also explains their interconnections. We improve on Evolutionary Epistemology, as launched by Popper and Campbell, by exhibiting the actual evolutionary mechanism. This feature of scientific discovery corresponds to what has been described as {\it Serendipity}.

Chapter 6 . The evolution of science according to Popper, Kuhn, Lakatos and Feyeraband - and the evolutionary thesis.

{\bf 6.1 XXth Century Epistemology}.

Sir Karl R. Popper (1902-1994) was the main leader in the development of a
modern approach in our understanding of the way in which science is constructed and grows. His key conceptual contribution was the emphasis on {\it "falsification"}[1] – a term used by Popper in its German connotation but unfortunately conveying somewhat unpleasant notions in its usual meaning in English. I have therefor suggested instead the
term "*invalidation*" which in English is precisely what is meant here.. No matter how many times a scientific theory has been successfully checked, one can still never regard that as proof that the theory will *always* be right, when tested under some new conditions, i.e. for some as yet untested value of some parameter On the other hand, even one failed test proves that it is at least partially wrong. One should always be looking for ways of checking out a theory, i.e. of {\it trying to prove it wrong}.

Another important modern epistemologist was Thomas S. Kuhn (1922-1996). He pointed to the role of the {\it paradigm} [2] providing an axiomatic logical foundation for the construction and growth of a scientific theory. The detailed components of the theory
are derived from the paradigm by logical inference (including {\it mathematics}, one form of such an inference machinery)..

When a theory fails the invalidation test, one will have to modify or replace the paradigm. Kuhn also pointed out a distinction between {\it normal science} and {\it revolutionary science}, the latter occurring in periods in which one is looking for a new paradigm.

Let us carefully analyze the conditions when a paradigm has to be replaced. Mostly, once the existing theory has failed a test, one should be on the lookout for a new theory, built on a new foundation – a new paradigm. The new theory should still yield the same results as the old one within the region (or the range of parameters) over which that old theory had been positively verified. At the same time, in the region outside of that domain of verified validity of the old one, the new theory should provide predictions different from those of its predecessor, starting with the need to fit those observations which had caused the demise of the predecessor, then going further than that (beyond the previous test's results) and yielding brand new predictions, such as can be tested by Popperian invalidation in their turn. Let us be more precise in the mathematical formulation of the appropriate constraints, when dealing with physical theories.

In the “scientific revolutions” of the early XXth Century, we have Galilean-Newtonian Kinematics leading to the concept of a mechanical ether (to carry the transverse wave-motion of Electromagnetic radiation, including light) failing the Michelson-Morley test in 1887. This then indirectly lead to Einstein's {\it “Special Theory of Relativity} (1905), a new paradigm, based on the invariance of {\it the velocity of light}. When one now, within the new paradigm, sets the velocity of light to infinity, Einstein's new kinematics yield the old Galileo-Newtonian ones. However, this also means that {\it as long as the relative velocities in a problem are small, as compared to the velocity of light} – the situation is similar to that of having an infinite velocity of light – and {\it the old theory should then represent a good effective approximation}. These two ways of looking at the transition between the old and new paradigms – two aspects of the same mathematical structure – these have to be present in every such post-invalidation replacement of a theory by a more encompassing one, valid beyond the limits of the previous region of validity. In the state of physics at the beginning of the third millennium AD, this is a constraint to be imposed on String (or “M”) Theory, as a candidate paradigm which would have to replace Relativistic Quantum Field Theory and General Relativity, when the domain of application is enlarged so as to include Quantum Gravity (i.e. around and perhaps beyond Planck energies).

The Special Theory of Relativity was itself invalidated when it was shown (1919) that light – the basic invariant in this paradigm - is accelerated and deflected in a gravitational field (e.g. when passing close to a massive star). It was replaced by Einsten's (1915) General Theory of Relativity (which itself has since passed successfully all tests throughout the entire XXth Century). The Special Theory's kinematics, coupled with Newtonian dynamics, making up the old paradigm in this example, are indeed recovered in the new paradigm by going to the limit defined by {\it setting Newton's constant of gravity to zero} in the General Theory. Equivalently, as long as masses are small, so that gravity is a weak force, working with Newtonian dynamics coupled to the kinematics of the Special Theory of Relativity (the old paradigm) remains a good approximation.

Quantum Mechanics is our third example from the early XXth Century. The old paradigm of Classical Physics failed, when Max Planck tried to account for the spectrum of black-body radiation (1900). Classical theory imposed an “ultra-violet catastrophe”, namely a tremendous increase in the short-wavelength part – contrary to observations.
The usual way of describing the spectrum involved grouping the various contributions according to the {\it action} carried – where {\it action} is an entity defined by Maupertuis and Lagrange at the end of the XVIIIth Century, dimensionally equivalent to the product [energy $\times$ time] or [linear momentum $\times$ length]. Looking at his summation, Planck noticed that the ultraviolet catastrophe would be avoided if the action were to exist only in discrete bundles of one fixed size, thereafter named {\it Planck's constant of action} h. This was a new paradigm with an obvious “temporary solution” look.

It was replaced by a more elaborate – though still obviously incomplete) paradigm in 1925, with the emergence of {\it Non-relativistic Quantum Mechanics}, the Quantum Mechanics of Schroedinger, Born, Heisenberg, and Dirac. The new paradigm embodies Max Planck's 1900 assumption of a {\it quantized} action, in “quanta” of size h. Quantum Mechanics exists in several equivalent formulations, due respectively to Schroedinger (“wave mechanics”), Born and Heisenberg (“matrix mechanics”) or to Dirac and Feynman (“path integrals”). To observe the recovery of the old paradigm from the new one is easiest done in Heisenberg's formulation, in which the paradigm is given by {\it commutation relations} between {\it conjugate variables} (i.e. a pair of quantities whose product has the dimensions of the {\it action}), known as the {\it Uncertainty Relations}, $PQ – QP = h$. P and Q are operators – a mathematical representation of operations, here two operations yielding different results depending on the order in which they are applied. Example: if C represents “cooking” and E is “eating”, then (assuming the operators act to their right, i.e. in CE, E acts first, then C) CE means “eat, then cook”, i.e. you can only eat yesterday's leftovers and {\it the new meal is left untouched} – while EC means “cook, then eat” and the new meal has been consumed. The difference CE-EC is therefore 'one new meal', the uneaten one in CE. The difference PQ-QP is thus “a portion” of {\it action}, and since action is now known to be quantized, the right-hand-side in PQ-QP has to consist of an integer number n of Planck quanta h. Classical Mechanics are recovered precisely, when h is taken to zero – or as a good approximation, when the quantities described by P and Q involve large actions, as compared to Planck's quantum of action h. So far for the notions developed in Popper's and Kuhn's approaches.

Imre Lakatos (1922-1974) introduced the idea of {\it scientific programs}. According to him, this is an important factor in identifying patterns in the development of a scientific discipline [3]. The XX-th Century for example; could be considered as “the Particle Century}, having started close to the 1897 discovery of the electron by J.J. Thomson and ended with that of the {\it top quark} in 1994.

Paul K. Feyeraband (b.1924), on the other hand, noticed the meandering path of advance and the halfhazard way in which results sometimes appear to come up, concluding that in scientific research “anything goes”. He went on to claim that “modern” Science, as restarted by Kepler, Galileo or Newton and boosted by Einstein, is not any better than Hopi Cosmology or than the Physics and Metaphysics of Aristotle; nor can Astrology be said to be a lesser science than Astronomy [4]..His arguments are generally not taken too seriously and yet probabilities do play a role

A vague linkage between man's range of ideas and the limitations due to Evolution was pointed out by K.Z. Lorenz (1903-1989). K.R. Popper first raised the hypothesis of {\it Evolutionary Epistemology}[5], followed by Donald Campbell [6]. They very roughly traced the evolutionary characteristics in the context of scientific processes of discovery.

With Aharon Kantorovich [7] I have presented the actual mechanism {\in through which the evolutionary process takes place. In an analysis based on the examination of a large number of examples, we pointed out the characteristics of such “mutations” and showed that the closest previous notice of its workings is represented by the notion of {\it Serendipity}, namely {\it “when going for A, arriving in B”}. The term is derived from “Serendip” – the ancient name of the island of Ceylon, nowadays the sovereign state of Sri Lanka. In a fictitious story, “The three princes of Serendip”, wonderful surprises keep occurring to these princes – hence the term.

{\bf 6.2 Evolutionary Epistemology}

We definitely believe that epistemology does belong in an evolutionary panorama. The view we present here fits with the ideas of Popper [5] and Campbell [6] in this context, but the actual implementation, or the precise manner in which Evolution acts here follows the ideas we presented some years ago – the Kantorovich-Ne'eman thesis [7] and their extension by both authors [8,9].

As in any evolutionary process, let us first point to the evolving cybernetics, the {\it control program}. That "DNA" of science is {\it the set of axioms or assumptions from which all predictions in that specific sector can be derived by logical deduction}. This is at the same time recognizable as represented by Kuhn's {\it paradigms}. Similarly, Kuhn's {\it normal science} (including the task of Popperian verification/falsification) represents here the element which fulfills the role of a routine manipulation of the program, necessary for errors to get their chance. One type of "effective" mutation" is realized when a theory (or paradigm) indeed fails the verification test. This failure means that one has made {\it an unwarranted assumption (i.e. a mistake) in taking the paradigm as holding, in a region of parameter-space where it had not been tested before}. To some extent, this is the analog of the "effective" bad mutations we mentioned ("type E) in which it is the environment which has "mutated" and caused some change in the selection criteria and constraints, i.e. an {\it extinction} in biological terminology.{\it This is a change in the environmental conditions, which has the effect of destabilizing the species within the relevant zone.} We shall refer to such a negative evolutionary selection process (or bad passive mutation) as a {\it type E} procedure.

At the same time, the search for a new paradigm may in itself involve "mutations". This type of mutation is included in a class known as {\it serendipity}. Columbus' "exploration of a shorter route to India" (section 5.3) was a mutational error which entered through the application of the Ptolemaic paradigm, with the mistakes it contained. At the same time, it was a "good" mutation, leading almost directly to the discovery of America, adding a large continent to man's home on Earth. In the case of the computer (section 5.8), the paradigm was constituted by Set Theory, combined with Symbolic Logic. The routine manipulation ("normal science") was constituted by the launching of Hilbert's "Principal problem of Mathematical Logic" or by Russell's "Principia". The mutational error was the paradox – and it led to a stable and "good" mutation, namely to Turing's machine and to the modern electronic computer. In all of these cases we would previously have invoked {\it serendipity} [7, 9, 10]. Note that conceptually, serendipity represents processes following orthodox neo-darwinism. We shall, however, refer to such action, when it occurs in epistemology, as {\it type S} (for {\it Serendipity}.

Lakatos' {\it research programs} [3] can now be seen as {\it the teleonomic a-posteriori reconstructions characteristic of an evolutionary drive}, the series of tactical advances which then together make up a strategic jump. "Exploring routes to India" is a title which could describe a series of ventures throughout the XVth Century; however, by retrospective viewing, we better call it "The Age of Exploration", crossing out India from the title, as it is this research program which brought about the discovery of America, instead.

As to Feyerabend [4], his exposure of the importance of chance indeed corresponds to a definite feature, namely {\it the random element} entering any evolutionary process. Seen in that light, however, {\it Feyerabend's "anything goes" conclusion is unwarranted} and should be replaced by the scientist's combination of two modes of operation, namely, on the one hand, "normal" research – and on the other, keeping an open eye on the look-out for possible serendipitous developments.

{\bf Chapter 7: The experimental discoveries in Physics at the beginning of the XXth Century}

{\bf 7.1: Serendipitous discoveries (the "good" mutations.)}

To check our evolutionary view of epistemology, we now examine some concrete cases.
We start with the experimental discoveries around the "turn of the century" decades of the XIXth -XXth Centuries: X-rays (1895), radioactivity (1896), the electron (1897),
the Michelson-Morley experiment (1887), the failure of {\it the theorem of the equipartition of energy}, a paradigm which had also explained the manner in which specific heats rise with temperature. The first three among these experiments explored new regions of physical reality, the world of molecular and atomic phenomenology, which had until then been either inaccessible or not known to exist. Thus, there were as yet no relevant theories to falsify in these regions, one was facing virgin ground. These are type S results.

The other experiments listed represent falsification {\`a} la Popper, in which Classical Physics failed the tests, a fact which then led to the collapse of the Classical paradigm and to the birth of several new ones, representing the foundations of Modern Physics. They are type E results. Two of these experiments (the Michelson–Morley experiment and the anomaly in the specific heat of solids at low temperature) were the "dark clouds" that Lord Kelvin used for the title of his famous April 1900 address to the Royal Institution of Great Britain [11]. The traditional story is that he was treating them as minor disturbances marring the beautiful panorama of XIXth Century physics (with the merger of electromagnetism and light, plus the derivation of heat physics from mechanics, using statistical methods) and that they would soon disappear… Any honest reading of the published text, however, shows Lord Kelvin to have been fully aware of the "clouds'" tremendous importance, of the collapse of the basic paradigms of Classical Physics, which they had caused, and of the difficulties in the search for new paradigms – a task which, however, was part of the legacy of the XIXth Century. Returning to our above list, we shall first review the three type S (orthodox mutation-caused) "discovery" experiments [12].

{\bf i. The discovery of X- rays (1895) – a type S "good mutation"}
Wilhelm Conrad R{\"o}ntgen (1845–1923), a German-Dutch scientist, was one amongst many physicists, around the end of the Century, who were investigating {\it cathode rays}. In 1888, he had provided experimental proof that the {\it convection} electric current (produced by moving electrical charges) is the same as the {\it conduction} electric current (e.g. in a wire, produced by a Voltaic battery or by a changing magnetic field). He had then been appointed to a chair at the University of W{\"u}rzburg, where he had started on this new program. Cathode rays had first been noticed by Michael Faraday (1791–1897) in 1833. In studying the effect of an electrical discharge through a rarefied gas, he noted a {\it glow} which increased with better rarefaction.

Julius Pl{\”u}cker (1801–1868), working in Bonn (1858) found that the glow, with a green phosphorescence near the cathode, can be displaced by a magnetic field, i.e. it must consist of electrically charged particles. Vacuum pumps technology having improved, Pl{\”u}cker's pupil Johann Hittorf (1824–1914) was able to observe the projection of a “shadow” on the anode, when an object was positioned between it and the cathode. This implied that these particles were entering the tube at the cathode end (which is why they were given the name of “cathode rays”) and were therefore charged with negative electricity. This was still disputed by most German physicists, following a wrong experiment by Heinrich Herz in 1892, claiming to show that the constituents of cathode rays were waves, not particles - until Jean Perrin (1970–1942) provided undisputable proof of their being negatively charged particles indeed (like many other scientists in France, Perrin started a dynasty – his son Francis Perrin was for many years at the head of the French Atomic Energy Commission).

This was the state of affairs when R{\”o}ntgen entered the scene, late in 1895. He was using an evacuated tube ({\`a} la Hittorf), which he had placed inside a black cardboard box. He had also prepared in addition a set of screens, made of paper with a layer of barium-platinum cyanide – a phosphorescent material, which he planned to use later in the experiment. To his surprise, one such screen, left near the box, started to phosphoresce. He inverted it, making the side with the phosphorescent layer face outwards from the Hittorf tube – and yet the phosphorescence continued. Putting some objects between the vacuum-tube and the screen produced surprising effects, including seeing the bone skeleton when he put his hand there. He had discovered X-rays; after some tests and two months of detective work, he could point to where they were produced - in the area where the cathode rays impinge on the glass walls. The rays were wave-like and it took another 16 years before they were finally identified as electromagnetic radiation with wavelengths in the range of 0.01 nm (nanometer) to 1 nm.

Viewed as an epistemological exercise, this story has all it takes to be evolutionary. The existing paradigm was the cathode ray story. R{\”o}ntgen activated a manipulation, some time later along that {\it normal science} program. This is where a “mutation” occurred, namely the {\it accidental} detection (by the screen, which happened to be there by chance) of a new effect. This effect now became part of the new paradigm. It thus corresponded to a “good” mutation. All of this is typical of a serendipitous discovery. What more could we need? As to R{\”o}ntgen, he was rewarded by the first Nobel Prize in Physics (1901).

{\bf ii. The discovery of Radioactivity (1896) – a type S “mutation”}.
The news of R{\”o}ntgen's discovery got everywhere in Western Europe and motivated a search for similar effects. Henri Becquerel (1852–1908) was the third in a dynasty of physicists, starting with his grandfather Antoine Cesar Becquerel (1788–1878), followed by the father, Edmond Becquerel (1820–1891), a mineralogist, in addition to his physics (the fourth generation has since also appeared on the French physics scene, namely Jean Becquerel (1878–1953)). When R{\”o}ntgen's photographs arrived at the French {\it Acad{\'e}mie des Sciences}, Henri Poincar{\'e} the mathematician and philosopher, displayed them in reviewing the Roentgen experiments. Henri Becquerel, who was in the audience, thought of the possibility that X-rays might be related to either fluorescence or phosphorescence, i.e. radiation emitted by some minerals after they have been exposed to light for some time: in fluorescence only while the absorption of light is occurring; in phosphorescence - continuously, once the sample has been

exposed to light and the emission triggered – going on for some time even after the stimulation source has been removed..

Becquerel was considering the analogy between the stimulation of fluorescence by light and the stimulation of X- rays by the cathode rays. He went home, where he had his father's collection of minerals, including fluorescent ones, which the father had used in a study of fluorescence and phosphorescence. Becquerel's intention was to test his conjecture of a parallelism. Selecting a phosphorescent mineral ({\it pechblende, containing uranium}), he exposed it in the sun daily, with a well-protected photographic film underneath. The film was guaranteed to be fully protected from the Sun for an entire day – and yet one could observe the mineral's silhouette on the film. After a few days of this routine, the weather changed and Becquerel postponed any further exposure, leaving the mineral and the film in a drawer. When the weather improved after several days, Becquerel took out the film and mineral again – and noticed that the film had been exposed nevertheless. This was a completely new indication, amounting to the discovery of a new phenomenon, consisting in the non-stimulated emission of yet another powerful radiation. Henri Becquerel was awarded with the Physics Nobel Prize in 1903, together with Pierre and Marie Curie (who had meanwhile joined the study of radioactive materials and had made the discovery of radium)

This case study again reflects straightforward serendipity – and in an evolutionary analysis it is a simple case of a {\it good mutation}, a type S step..

{\bf iii J.J. Thompson's discovery of the electron (1897)}
This was in fact more of a “final” proof of the electron's existence, than a discovery.
The latter could be said to have occurred back in 1833, when Michael Faraday first noticed the “glow” near the cathode in a partially evacuated tube, later identified as {\it cathode rays}. The difficulties, at the time, in achieving a good vacuum, made it difficult to test the constituents of these cathode rays. Some experimentalists observed the deflection of the cathode ray under the action of either electric or magnetic films – and concluded that cathode rays involve negatively charged particles. This view, however,
was disputed in Germany, where Heinrich Hertz published a negative result with respect to the sensitivity of the beam's constituents to electric and magnetic fields. To Hertz, the constituents were therefore (electrically neutral) waves, whereas to Pl{\”u}cker (1858)
they consisted of electrically (negatively) charged particles. It then became important to fix the nature and parameters of these constituents. Now, after Perrin's intervention, the entire program is one of several efforts at improving conditions. Meanwhile, in Cambridge, J.J. Thomson managed to improve his vacuum and could thus act on the beam with both electric and magnetic fields, adjust them so as to cancel – and extract the precise values. The outcome was the identification of the electron and the resulting measurement of its e/m value. As a Lakatos program, this was the opening move in what was to become a list of some 100 particles. J.J. Thomson received the Nobel prize in physics in 1906.

Epistemologically, this is “normal science”, comparable in biological evolution to the uneventful overall population increase, with the RNA – DNA copying and reproduction
machinery helping to preserve the “normality” conditions and opening from time to time new

evolutionary vistas.

{\bf 7.2 "Extinctions": the Popperian experiments}
{\bf i. The Michelson–Morley experiment "extinguishes" classical kinematics}
Albert Abraham Michelson (1852-1931), the first American to be awarded the Nobel Prize in Physics (1907), was to provide both the weapon which demolished the paradigms of Classical Physics and the first crucial test for the Special Theory of Relativity, Albert Einstein's revolutionary new paradigm (June 1905) – which passed it successfully. Note, however, that one connection with Einstein was present from birth: both are named Albert because both had grandfathers named Abraham (Abraham Einstein of Buchau,
1808-1868 ; Abraham Przylubski of Inowroclaw – Michelson's maternal grandfather).
In Western Europe and America, starting around the middle of the XIXth Century, "emancipated" Jewish families, selected for a boy a 'gentile' name, on top of the Jewish name assigned to him at his circumcision, assuming that some day this would help him enter some white-collar profession, outside of the ghetto or of the Jewish Community services. The 'gentile' appellation was selected for various practical reasons so as to have the same initial as the Jewish "circumcision name". After Queen Victoria's wedding to Prince Albert, this name became the most popular 'gentile completion' to 'Abraham'.

Albert Abraham Michelson was born in Strzelno (then Prussia, now Poland) the son of Polish-Jewish immigrants driven away by anti-Semitism and pogroms - a family which arrived in California in 1856, settling in Murphy, a gold-rush mining town, moving to Nevada some years later. In a well-researched biography of her father, Dorothy Michelson-Livingston relates the anecdote of Michelson's admission to the Naval Academy at Annapolis. On being offered by US President Ulysses S. Grant a vacancy at the Naval Academy, for a cadet from the Territory of Nevada, Thomas Fitch, the local US congressman, organized a concourse and test to select the candidate. Michelson was one of three boys who tied for first place; Fitch selected one who was recommended by the congressman's predecessor in Congress, but compensated by writing to the President and asking for an additional vacancy – justifying his demand by stressing the leadership role of Albert's father in the local Jewish community - and Fitch's hopes that Albert's admission would help get votes for the Republican Party (rather than stressing Albert's remarkable school record, for instance). The Fitch letter is reprinted in the biography. A.A. Michelson soon became a science instructor at Annapolis, started research in optics and became interested in precision measurements of the velocity of light. For these purposes he developed an {\it interferometer}, which became his main tool. Leaving Annapolis in 1880, he went to work under Hermann L.F. Helmholtz (1821-1894) in Berlin, the scientist whose contributions span Ophthalmology, Otology and Physics (he discovered the conservation of energy). Here in 1881, Michelson performed the first version of his famous {\it ether drift} experiment – measuring the velocity of the Earth relative to the {\it ether} – with a {\it null} result!. He had meanwhile greatly improved the precision in the value of the velocity of light, a result he continued to improve throughout his lifework. As to the ether-drift experiment, Michelson kept repeating it under ever more precise controls, especially after being joined by E. Morley at Case Institute of Technology in Cleveland in 1887 – still with null results. Note that a classical estimate indicated that even if the Earth had nothing but its velocity around the Sun, this should have been easily detected.

The presence of an 'ether', filling up the whole of space – whether interplanetary, interstellar or intergalactic - was considered essential for the propagation of light and of all other types (i.e. frequencies) of electromagnetic radiation. These being all transverse waves, the medium had to behave somewhat like a solid. Lord Kelvin and others devised various models for such an ether. Splitting a beam of light and sending the two components simultaneously in two orthogonal ("x//y") directions, with reflecting mirrors disposed on these axes at equal distances from the center, Michelson measured the difference in the arrival time of the reflected beams, i.e. the length of time needed by each of the two orthogonal components for its complete return trip - this should have yielded the earth's velocity with respect to the ether, according to the Classical paradigm for the addition of velocities. Similarly, traveling in a ship at sea, you can measure the ship's velocity by dropping a stone into the water and observing the (roughly) elliptical wave front generated by the stone's impact, measuring after a few seconds your own distance from at least four points along that wave-front, on the orthogonal coordinate axes, with the {\it y} axis aligned with the ship's motion. The calculations on page 24 of ref. [13], dealing with the actual Michelson-Morley experiment, would also hold precisely for the sea-faring analogy we have just described.

{\bf ii. The "Special Theory of Relativity" as the post-extinction emergence of a new species – the new paradigm}
The "explanation" of the null result of Michelson's {\it ether-drift} experiment was provided by the 26 years old Albert Einstein (1879-1955), employed as "expert III class" at the Swiss patent office at Bern, in the fourth (June 30) and fifth (September 27) papers of his {\it "miraculous year" 1905}. It was a new paradigm, the principle of the {\it invariance of the velocity of light in inertial frames}. This now replaced {\it Galileo's law of Inertia}, which had later become {\it Newton's first law of motion}. For bodies moving at velocities small relative to the velocity of light, the old rule of addition of velocities (resulting algebraically from the Maupertuis postulate of the {\it Action}'s invariance, in the present case, under the {\it Galilean group}), for instance, provides a good approximation to the new formula and thus may still be used for small velocities. Approaching the velocity of light, however, the kinematics algebraically display {\it invariance under the Poincar{\'e} group}, also known as the {\it inhomogeneous Lorentz group}. Note that the two names are those of two senior mathematicians or mathematical physicists who were very close to discovering Einstein's solution on their own – and yet did not make it, because they did not dare modify our notions of {\it time} and of {\it simultaneity} – a consistency requirement of the new paradigm.

Seen from the viewpoint of Generalized Evolution, the emergence of a new paradigm after the Popperian "extinction" of the previous one, is analogous to the emergence of new species after each paleontological extinction – e.g. the emergence of the {\it mammals} upon the demise of the dinosaurs. We saw that the latter was caused by the failure of these super-heavy saurians in adapting to the new atmospheric conditions created by the impact of the collision with some large meteor. The mammals, the small ones which then existed, fared much better and naturally took over. Similarly, the Galileo-Newton inertia paradigm underwent an {\it extinction blow} when confronted with the new kinematical conditions of Michelson's ether-drift experiment. Einstein's Special Theory of Relativity, the new paradigm, then played here the same role played by the more adaptive mammals, who took over in the transition between the end of the Cretaceous and the beginning of the Tertiary. Note that Einstein got to his result by a direct confrontation of Galileo-Newton kinematics with Maxwell's equations and identifying the kinematical paradigm behind Maxwell's equations. He was, however, aware of the incompleteness of his new paradigm, as long as it did not encompass Newton's dynamics – and therefore almost immediately went to work on a new paradigm, capable of replacing the entire theory of Newtonian Mechanics. We return to this development in section 9.1.

{\bf iii. Black body radiation and the "extinction" of the Energy Equipartition paradigm}
The "beautiful panorama" of XIX-th Century physics (marred by the two dark clouds) - as drawn by Lord Kelvin in that speech to the Royal Institution, referred to two XIX-th Century successes, which had "done away" with two traditional chapters of physics: the discovery that {\it light} is a subset of Faraday-Maxwell electromagnetism and the derivation of Heat (or thermodynamics) from the application of statistical methods to mechanics.

{\bf Bibliography

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. AK YN
. YN Royal Netherlands//
. AK book
. YN soft order
. Kelvin
. Segre book
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The Model:-- Biological Evolution

-- Biology – Linneus

- Darwin, Wallace, Spencer
- Mendel & Genetics
- Schroedinger, Szilard, birth of mol. Bio.
- Watson, Crick, DNA etc genetic code
- Drift, Punctuation, [new stuff?]
- Extinctions

The evolutionary Paradigm *----------------------- |
Characteristics |
b Teleonomy |
a Tinkering |
Far from equilibrium ----| -----dissipation
c 2nd law, micro macro **| -----complexuty
ana,ogy with blacu hule |
Symbolic Logic presentation |
M-type and E-type * ------------------------- |
E=type; infi +/- *, integrated * = 4 stas
The Generalization
Emergence of life
Nucleosynthesis [Mendeleev – Segre]
[Hoyle- Fowler, Burbidges]
Stellar & Galactic
Cosmological: anthropic strong
anthropic weak
Harrison
Smolin
Society [incl. Erathostenes & Russel]
The role of science ***
Ideas – the Judeo-Christian ethic ****
Ideas -- Evolutionary Epistemology
Serendipity as M-type *****
Invalidation as E-type ******)
4 roles: Kuhn. Popper. Feyeraband- Lakatos[*******]

* 7 innovations

Appendices

Cosmology – [Einstein –de Sitter – Lemaitre
Hubble & the Expanding Universe
Gamow s Steady State
Penzias 3 deg
The many-cores idea
[Ne’eman – Novikov quasar model]

[Ambartsoumian]
Inflation [Guth, Linde, La & Steinhardt]
Accelerated Expansiom