Introduction

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As is well known, modern science represents the heritage of the late Middle-Ages philosophy, in particular of the Oxonian School. As the great American philosopher Charles Peirce said, the true followers of the late scholasticism are not modern philosophers but modern scientists. We will consider later the reason of this surprising statement. However, already here we have a critical point: How is this derivation or lineage to understand? Is it a simple instance of the more general rule according to which special sciences are born as branches from a common tree of knowledge represented by philosophy, or there is something more in this derivation? Moreover, how can one envisage the relationships between science and philosophy once that this break has been produced?

Let me first consider what are the common points between late scholasticism and modern science that could explain such phylogeny. There are at least three common points:

- Methodologically, scholasticists (not only late scholasticism) as well as modern scientists avoid total explanations and focus their work on specific aspects of the human enterprise known as knowledge. For this reason, both groups of scholars situate their activity in a public and academic context, in a school. Under this respect, both scholasticists and modern scientists conceive their activity as open to an endless progress. This is in a bizarre contrast to modern philosophers, who in general see their activity as individual, who in general do not strongly communicate with their colleagues, and who try to give systematic and sometimes total answers.

- The second point is the search for explanations that are as far simple as possible, according to the known Ockhamist principle: *entia* *non multiplicanda praeter necessitatem.* This is even the ultimate reason of the Copernican revolution and of the birth of a mechanical science. How is this principle to understand? The Oxonian school understood it in a methodological sense and so also Copernicus. However, there are reasons to believe that already Galilei and later on Newton understood this principle in a ontological sense, as the search for the ultimate elements of reality which were understood in atomistic or corpuscular way. What is really amazing is that the great English philosopher John Locke, who influenced the birth of the liberal State in Great Britain, and who gave an important contribution to studying the mechanism through which concepts are born and transformed in the human mind, accepted this point of view and tried to find in it the ultimate genesis of concepts.

- The third point in common concerns the way late scholasticism and modern science see the relationship between different regions of knowledge. Late scholasticism represents the first instance of an experimental science, and under this respect the connection with modern science seems evident. However, this point has been understood in a sense that in my opinion is not completely correct. As the 20th-century epistemology has shown (especially through the work of Alexander Koyré), modern theoretical science in its formulations does not directly depend from empirical data. On the contrary, in general the theoretical formulations give the first hint for doing experimental research, and this represents often a posterior confirmation of those theories, already advanced on a hypothetical plane. The issue is in my opinion rather this: Late scholasticism had emancipated natural science, especially physics, from metaphysical or theological considerations. This does not mean that metaphysics should play no role in science, as we shall see. The point is that science could no longer be considered as a consequence, in a top-down derivation, of some first principles situated in a far heaven. Late scholasticism opened the path to modern science allowing for a bottom-up flow of knowledge. This does not mean, again, that theories are consequences of data, but that theories have to *account* for empirical data and not for previous general principles.

It is well-known that modern science come out from a major break represented by the Galilei's innovative work and his successive condemnation. It is not time and place now and here to enter in this very difficult problem. I wish only to stress that at this precise time, let us say beginning of the 17th century, philosophy was caught off her guard. There were important philosophical contributions to the birth of modern science at that time, for instance, by Francis Bacon or the Italian naturalistic school (Telesio, Bruno, Campanella), but it is an ascertained historical fact that none of these contributions can be considered as a direct antecedent of Galilei's work. The most important difference is this: Galilei, following Oresme, Benedetti and others, had replaced the formal language of the Middle-Ages, that is logic, with mathematics. And mathematics played no role in the philosophical constructions of the aforementioned philosophers. However, I recall here that the first one to have thought of mathematics as the main tool of science was again a Middle-Age philosopher: Roger (not Francis) Bacon, and this already at the beginning of the 13th century. Now, mathematics is a far more plastic tool than logic is. Moreover, it allows quantification of physical dimensions. Peirce said that ancient science was founded on dualistic and qualitative oppositions, like that between rest and motion. In this qualitative stage of science, only properties of things are considered, and a logical language suffices. A more developed science needs a lot of intermediate situations between these opposite poles (through acceleration, for instance), and this can only be provided by quantification of physical dimensions, i.e. by mathematics.

This seems to me the initial core of the misunderstanding between science and philosophy. Actually, at that time no philosophy of nature was built (an exigency that was deeply felt in the *Collegio Romano*) that could face this new way to do science. Only two major philosophers tried this: Descartes and Leibniz. Descartes produced a philosophy of nature that did not catch the new essential aspect (mathematics), and this notwithstanding the fact, or perhaps as a consequence of the fact, that he pushed a geometrization of Nature to the last consequences. In fact, as shown by Alexander Koyré, this was done at the expense of dynamics, that is, of a temporal dimension, and the ultimate reason of the superiority of mathematics, as I have said, is in this ability to account for intermediate situation that are in general of dynamical type (as it is evident in the case of acceleration).

Leibniz tried to oppose to the rising mechanism by introducing the concept of an intrinsic energy present in matter. The idea was very good and it is well known that it gave rise to the French school in the 18th-19th century which consistently introduced the concept of energy in physics and the Lagrangian function, whereas Newton had assumed that matter is only characterized by inertia and that for this reason it can be made active, if not already in a state of motion, only by forces that act from the outside (he finally supposed that these forces are due to the direct action of God). However, it is an historical fact that physical science was built upon Newton's principles and not Leibniz's ones.

I mentioned that modern philosophy, differently from scholastic philosophy, was practiced as a systematic and total body of knowledge. It is interesting to notice that already Descartes and his followers, instead of following a formal but open (and "dynamical") method like that introduced in physical sciences, drew their inspiration from the axiomatic method of the Euclidean geometry, as it is evident with the Spinoza's system. This is not the place for examining such a wide problem as the development of modern philosophy, but it is a fact that we have on the one hand a "closed" continental philosophy, which became dogmatic, and, on the other, an Anglo-Saxon current which on the contrary pushed a form of scepticism to the extreme consequences.

Kant is to a certain extent the beginning of a new season of the relationships between science and philosophy. I will not enter in these difficult questions, and I hope that somebody will do this. I only wish to point out two specific problems. The first is well known: Kant was unsatisfied with both the continental philosophy, which felt as too much dogmatic, and with the Scottish scepticism, which he saw as too much corrosive for science. Moreover, Kant sharply distinguished between science and philosophy (i.e., metaphysics) supporting the idea that physical science leads to results and is cumulative whereas metaphysics cannot produce definitive results but rather represents the hopeless human effort for gaining a whole understanding of the world. The idea that Kant had of metaphysics and philosophy was strongly dependent on what metaphysics became in modern times, that is, again, a systematic enterprise (one should not forget that Kant had followed himself in his youth the systematic and dogmatic philosophy of Wolff). On the other hand, being the son of a time in which physics aimed to represent a body of certain and indisputable knowledge, he was struck by the endless discussions dominating the history of modern philosophy, especially when considering the two already mentioned schools. If we consider this issue retrospectively, after the contributions to epistemology given by Kuhn and Popper as well as after the great scientific revolutions of the 20th century, it is evident that science is not as cumulative so as it seemed to Kant, and that the scientific enterprise come back again and again to old issues, sometimes making again use of theories that were beforehand discarded. This is evident, for instance, in modern cosmology, where one is now introducing antigravitational forces and consequently a type of cosmological constant, already proposed by Einstein and successively considered by himself as the greatest error of his life.

On the other hand, it is not true that philosophy does not proceed. It does, in fact. For instance, nobody would today support the body of Wolffian or Humean schools in philosophy of science. However, the nature of the philosophical problems, their abstractness, and the nature of philosophical methodology, which is strongly critical, leads to the misunderstanding according to which here there were no progress.

As a matter of fact, after Kant philosophy divided in two mainstreams: On the one hand, we have the rise of German idealism, representing a strong criticism against the mechanistic view of the world but simultaneously also an overstatement of the systematic aspect of modern philosophy. On the other hand, we have the positivism, and later on neopositivism, which is characterized by a strong rejection of metaphysics and by a certain acritical mimicry of the scientific enterprise as such. This last current has actually dominated philosophy of science up today.

Actually, there was also a third current, paradigmatically represented by Ernst Mach, who tried a critical philosophy and history of science. I will not support as such Mach's philosophy but rather point out a certain style of approaching philosophical and physical problems. As a matter of fact, advancing a strong criticism against Newton's understanding of space and time, in terms that are reminiscent of Leibniz's original criticism, Mach opened the path to the formulation of special relativity, as Einstein himself acknowledged. Mach also proposed to substitute the concept of an external force with that of an interdependence between the relative location of different bodies, and, by criticizing Newton's interpretation of the bucket experiment, proposed that masses as such can be understood as equivalent to forces. It seems to me that this is exactly what Einstein did with the general theory of relativity. For reasons that are not completely clear, and which may depend on historical contingencies of Germany, this school had to my knowledge no significant successors in the 20th century, apart neopositivism. However, Mach's reception by neopositivism, so far I can understand, was rather of epistemological colour and less centred on the main issue, that is, the critical confrontation with science.

However, the aim of this short introduction is not to present a history of these problems but rather to point out some critical moments of the history of the relationships between science and philosophy and give some hints to the following discussion. For this reason, I would like to stress two temptations in contemporary science. The first one is the temptation of closing the circle. This is expressed paradigmatically by Albert Michelson, who in 1894 probably reported Kelvin's opinion. Accordingly, the latter believed that physical science was already accomplished and that the future job only consisted in a more precise determination of some Nature's constants. This is surely surprising, given that few years thereafter relativity and quantum mechanics changed our understanding of the physical world. The second temptation is to rely too much on formal inferences. I see sometimes both temptations in play in contemporary physics, especially when one speaks of Great unification or of Theories of everything. I wish only to recall that late scholasticism and modern science were characterized from the start by a certain refuse of total explanations and of the use of abstract (top-down) reasoning as a way to arrive to solid scientific results.

Let us then come to the role of philosophy in the actual context. It is my opinion that science and philosophy, if detached one from another, can produce harm for both disciplines. Philosophy, when detached from science develops a strong tendency to an autoreferential body of knowledge that is based at the end on definitions. Many philosophers think that the task of philosophy is to define precisely some basic terms, like cause, effect, agent, body, and so on, and then to proceed by speculating about their relationships and consequences. The exact definition of terms is an important task for philosophy, but, when detached from scientific enterprise, it becomes a battle of words.

On the other hand, science without philosophy, as we have seen, runs into an uncritical understanding of its work and into the elevation of its theories to ultimate truths about the world. On the contrary, philosophical principles and assumptions, though do not have a direct scientific relevance, play or should play a central role in science. I limit myself to two examples. Einstein, Podolsky, and Rosen's assumption of realism in their famous paper published in 1935 is a philosophical assumption. Assuming or rejecting this principle, together with some other physical stuff, has huge consequences on the physical theory itself, and I think that an important part of the history of quantum mechanics can be seen as a commentary to this paper and to this principle. On the other hand, I am sure that without a physicist with a strong philosophical background like Niels Bohr able to formulate the Complementarity principle, quantum mechanics be remained as a conglomerate of different techniques and methods, without becoming a true theory. Let me add that at that time the absence of philosophers perhaps did not help to advance much more on this path, and as a consequence quantum mechanics still presents a lot of interpretational problems that up to now have not been solved.

Since we are here for allowing confrontation between science and philosophy, let me finally resume what can be considered in the last end the philosophical point of view which I would like to support, and therefore the specific contribution of philosophy. It is not fortuitous that I mentioned the reality principle of Einstein and co-workers. I am sure that Einstein was in error about the specific problems raised by quantum mechanics. But the general lesson remains. The metaphysical, let me say: the good metaphysical, point of view from Plato through the Middle-Ages up to today is a realistic one, and this in the double meaning of the word. As a realism of the world and as a realism of what, in a modern language, may be called its laws. There have been and are schools that have tried or try to oppose to this point of view: nominalism, sceptisism, a large part of epistemology, and so on. But they were and perhaps still are rather in minority and even the idealistic school in Germany, so far I can understand, has maintained in some way a realistic point of view. I wish to stress that also the modern science's point of view was realistic. Sometimes a rough realism, when Galilei spoke of the mathematical language of the world and Newton of the corpuscles as the last elements of matter. Today it seems sometimes that an idealistic or phenomenological point of view, as in quantum mechanics, is growingly important in science, or a form of weak realism as the invariances of Nozick.

Let me say that if science and philosophy wish to meet, in my opinion they should do on this common ground. Obviously, after the experiences of the 20th century, this problem must be faced in a critical way.

The present historical moment is as stimulating as many in the past (and perhaps even more), since a huge amount of scientific disciplines (from quantum mechanics to cosmology, from complexity and cybernetic to biology) are just presently opening new and promising perspective on the natural world. In this volume some interesting scientific findings and philosophical insights are put at work in order to offer new stimuli for the dialogue between science and philosophy. Two contributions by myself try to grasp some fundamental features of life as such by taking into account recent suggestions from both molecular biology and physics, with the aim of proposing some insights for what a living being essentially is. J. Barrow, starting from the present cosmological knowledge, suggests a way to establish the place of human civilisation in the universe following three points of view: according to the ability of a civilization to manipulate larger and larger environments (planetary, stellar or galactic scales); on the basis of the ability to manipulate smaller and smaller entities (human, genetic, molecular, atomic, nuclear scale and so on); and finally considering the ability of manipulating more and more complex systems. The issue of emergence is addressed by G. Ellis. The point is that emergent complexity has causal effectiveness that is not fully reducible to physics and chemistry. This is even truer concerning human intentions. The theme of the relationships between scientific laws and laws of nature is the focus of the contribution by M. Ghins. The perspective of the author shows how scientific laws require metaphysical considerations about real natural dispositions. The work delivered by B. Heap and F. Comim offers stimulating perspective on how science and technology, human sciences and Christian values can be successfully integrated in a perspective focused on the often sidelined problems of overconsumption and profligacy in developed countries. G. Tanzella-Nitti gives us a constructive proposal for harmonizing theological reflection and scientific enterprise, providing useful information on how scientists may look at theology and theologians at science. All that seems to me to really open new opportunities for a fruitful dialogue between science and philosophy

Part I

Contributions

1

Autarchy and Openess in Living Systems

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Hebb postulated that a central requirement for living beings is the relative independence from stimuli. The Landauer–Bennett information–theory theorem can provide a theoretical basis for this fundamental feature of life. It is shown that living organism alternate periods of autarchy and periods of entropic and energetic openess. Two main processes are used in order to reduce the differences between the result of the organism's autonomous computation and the external stimuli: Either a mechanical assimilation of the self by the environment or the accommodation of the environment to the self.

KEYWORDS: Self; autarchy; openess; assimilation; accommodation; mutual information; anti–feedback; representation.

The most important problem in understanding living beings and the one that still represents a true mystery is the relative independence of "internal choices" from external stimuli (see [Hebb, 1949]; see also [von Hayek, 1952, 10–11.]), the so–called *equivalence of stimuli*, already introduced in psychology by Lashley [Lashley, 1942]. Similarly, Bernstein acknowledged that the relationship between movement and the innervational impulse that evoke it was not univocal, in the sense that a given impulse can produce completely different effects under different conditions (see [Jeannerod, 1988, 27–28] and [Jeannerod, 1999]). An information–theory theorem can represent the key for understanding this basic structure of living beings.

It is the Landauer–Bennett theorem, according to which it is possible to process information without energy expenditure provided that there is no information selection [Bennett, 1973, Bennett, 1982] [Landauer, 1961, Landauer, 1996]. This assures the possibility of information processing in complete autarchy, that is, without dependence on previous physical conditions. As a matter of fact, already [Hebb, 1949, 60] understood that a necessary requirement for the independence from external stimuli is the possibility for the organism to act, in some temporal windows, as a closed system, even if at that time the mechanism could not completely be understood. For this reason, he [Hebb, 1949, 121] introduced the concept of *intrinsic* organization of cortical activity as opposed to the organization imposed on the cortex directly by sensory events. This line of research was also further pursued by Maturana and Varela [Maturana and Varela, 1980], who spoke of the neural circuit as a closed system.

In order to understand this feature, let us start with an ordinary complex system. In such a system, there is a continuous energetic and entropic flux from the environment to the system and vice versa. Obviously, the conditions that give rise to a complex system are in general very specific. For instance, Bénard cells can come out if two plates above and below some fluid are warmed up to a certain critical temperature. However, these conditions are not controlled by the system and in general give rise to a deterministic output, even if some aspects of the process (like the sense of rotation of each cell, though the ensemble of the cells rotate according to precise rules) are not specified. Completely different is the case of any living organism. Here, a membrane or some other mechanism assures a sharp division between self and non–self, so that certain exchanges with the external environment are controlled [Llinás, 2001]. Such a structure allows for the possibility that certain physical mechanisms of the organism are protected against external influences, and can therefore become the physical support of an autarchic computation. In the simplest case, a computation mechanism can be seen as a complex system that, led out of some equilibrium situation, will spontaneously evolve up to another equilibrium situation or minimum. This model have been largely employed for the domain called *computational brain* [Churchland and Sejnowski, 1992, Churchland, 1995]. The critical point is that a complex system has in general several minima, and, even if there is a best minimum, locally perhaps there are other minima that are more easily accessible [Kauffman, 1993]. There are very easy examples of systems with several stable states (multistability). For instance (see [Haken, 1977, 105–113]; also [Haken, 1991]), let us consider a one–dimensional system ruled by the classical equation

$$m\ddot{q} + \gamma\dot{q} = F(q) \ , \tag{1.1}$$

where m and q are the mass and the position of the system, respectively, $\dot{q}$ its first time derivative (its speed), $\ddot{q}$ its second time derivative (its acceleration), F represents some driving force acting on the system while γ some damping force. Assuming that m is very small and damping very large, we may neglect the first term on the lhs, and by choosing an appropriate time scale

$$t = \gamma t' \ , \tag{1.2}$$

we may also eliminate the damping constant γ, so that Eq. (1.1) can be written in the simplified form

$$\dot{q} = F(q) \ , \tag{1.3}$$

Equations of this type are very common in ecology or biology, where they describe the multiplication of cells or bacteria. We can consider in particular a system subject to a potential V, such that

$$F(q) = -\frac{dV}{dq} \ . \tag{1.4}$$

If we consider the case of an anharmonic oscillator, the force F is given by

$$F(q) = -kq - k_1q^3 \ . \tag{1.5}$$

k and k_1 are here two parameters. Then, the equation of motion reads

$$\dot{q} = kq - k_1q^3 \ . \tag{1.6}$$

For $k < 0$ see Fig. 1.1 (there are here two points of minimum).

Let us suppose that the process of falling in a minimum is initially completely random. Obviously, the protected system will fall in an arbitrary point of minimum, provided that it is easily accessible. This “choice” by the organism will be translated in some effective operation (will “switch on” some mechanism, often represented by one or more proteins) where some work is done [Kauffman and Clayton, 2006].
Here, the energetic and entropic flux is again allowed. It is interesting to recall that Ashby [Ashby, 1956] understood cybernetic systems as informationally closed and energetically open.

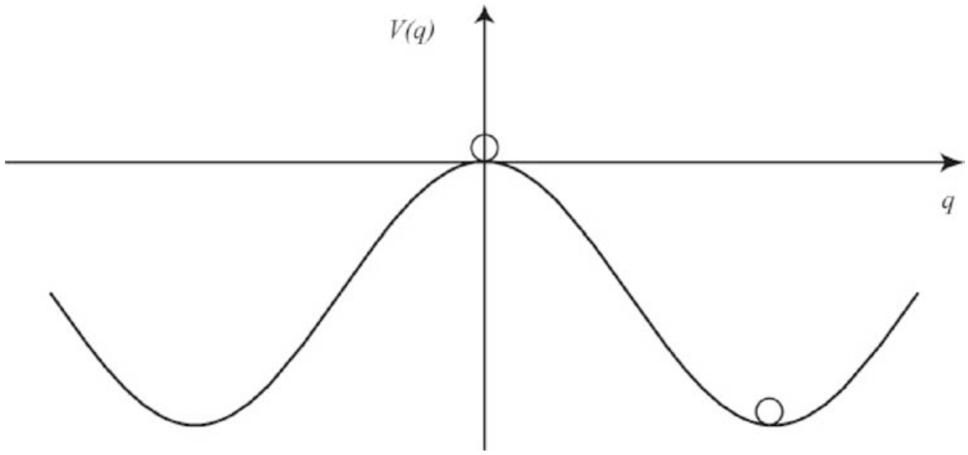

Figure 1.1: A ball initially in equilibrium rolls successively and randomly down to the minimum on the right, where it remains trapped if there are not sufficiently strong random fluctuations of the environment.

In the case of a bacterium, this work could be the movement of a certain cilium for swimming or flying in the direction (or in the opposite direction: in most simple case we only admit two possible motor outputs) of a certain chemical or temperature gradient. However, due to the difference between self and non–self, this choice will in general have some feedback consequence on the organism (here we have again entropic and energetic exchange, that is, stimuli are not subject to the organism's control): The choice will bring the organism to some energetic source or it will not. So far the choice is in accordance with the (inertial) self–maintenance of the organism, there are no reasons to move from the chosen minimum and the organism's choice is awarded. However, if the feedback is negative, the organism receives a stimulus that is somehow in disagreement with the chosen minimum.

When such a disagreement is present, from the "viewpoint" of the organism it faces a negative stimulus (a plus or minus big shock). However, from the "viewpoint" of the environment, the same phenomenon is a pure mechanical action. In general, when there is such a disagreement between self and non–self, at an abstract level two solutions are possible in order to reduce its amount. Either the non–self assimilates somehow the self. The most paradigmatic case is when the organism succumbs. In general, such assimilation is accomplished by brute, mechanical force, and has some disruption of the organism as a consequence. Obviously, the environment comprehends also individuals of other species and other individuals of the same species, and it can very well be that the organism dies because it is the object of some intelligent predation. However, it does not matter how intelligent this planification may be, the direct effect on the organism is always of mechanical type, so that, from the point of view of the organism any effect of the environment on it is of the same nature. Let me introduce an example about high organisms, even humans: somebody may plane very accurately and intelligently a homicide. However, at the end such a plane, in order to be effective, will be translated in some mechanical effect on the victim, for instance, a shot. This is the *direct* effect of this action on the victim.

The other possibility is that the organism tries to modify its status. In this latter case, the computational device of the organism through the shock is again set off of equilibrium, an autarchic random search is begun, and the cyclic process is run again. Such a process is evident during epigenesis [Waddington, 1974], but is a universal feature of any organism. The ultimate reason of such a new computation is to provide the organism with a suitable representation in order to somehow (even to a tiny extent) modify its environment by retroaction on it, that is, to accommodate the non–self to the self (see [Baldwin, 1894, Baldwin, 1902]). When speaking of representation, it is not necessary to think at something especially complicated: for instance, Gallistel [Gallistel, 1990] has shown that a simple oscillatory device in a unicellular organism can provide a rudimental representation of time.

In other words, in general representations are not produced for picturing something but for being focussed on something, which is the target of the organism. Such an external target is the referent relative to the representation. That is, a representation is a representation of an organism *for* a referent [Peirce, 1894]; [Auletta, 2002] and [Auletta, 2005a].

When organisms become complex, impressive evidences of such behaviour can be found. The organism may even try to manipulate environmental effects for inducing changes on its conspecifics. I recall here, at ontogenetic level, *stigmergy*, that is, the indirect influence of an individual on one of its conspecifics through a certain environmental modification that can affect the latter [Bonabeau, 1999], and, at phylogenetic level, *niche construction*, that is, the way populations of organisms can establish feedback effects on their own evolution by carving out the environment according to their needs [Oyama, 2001].
In general, many intermediate situations between the extreme of a pure mechanical disruption of the organism and an innovative transformation of the environment are possible, and finally both aspects are always

present.

Supposing that the organism has some matching (it is always a matter of degree) with the external conditions, we say that the organism *shares* some information with its environment. In this case, according to the previous examination, we also say that the organism has some representation of the external environment. The technical tool for information sharing is mutual information, defined as the amount of entropy or disorder of the organism minus the conditional entropy of the organism on the environment, that is,

$$I(O:E) = S(O) - S(O|E) \ , \tag{1.7}$$

where $S(O)$ is the entropy of the organism O and

$$S(O|E) = S(O,E) - S(E) \tag{1.8}$$

is the conditional entropy of the organism relative to the environment E, that is the total joint entropy $S(O,E)$ of the organism and the environment minus the entropy $S(E)$ of the environment (the conditional entropy is intuitively the degree to which the order of the organism does not depend on the environment). It is important to stress that the mutual information is only a degree of matching and does not suppose any information transfer between environment and organism [Auletta, 2005b]. I recall that the hypothesis is that the organism processes information in an autarchic way and that only responds in an adequate way to a given stimulus. A world where such transfer were possible, would be a Lamarckian world, that is, a world where the organism's reactions are *directly* structured by the environment.

I stress here that the hypothesis of a membrane and of an autarchic information processing are strictly related. In fact, without such a membrane the computation would be dependent on the input (on the stimulus), that is, on the external physical conditions, and the output would be mechanically determined. This is one of the most important flaws of the artificial intelligence, and to a certain extent also of artificial life, a flaw that, surprisingly, these disciplines have in common with behaviourism. In fact, it is not the complexity in the input elaboration (eventually through hidden or intermediate computational unities) [Rumelhart, 1986] to be the decisive issue. Actually, also in robotics one tries to let pattern of activity emerge [Mataric, 1992, Hendriks-Jansen, 1996]: Robots, for instance, can act following environmental landmarks and slipping from the behaviour specified by a landmark into a behaviour specified by the next, rather than travelling from one landmark to another. However, this does not supply for the most important feature of living beings: Error correction. The separation between self and non–self and the autonomy of the computational process provide for error correction, which here can be seen as an optimization process in which the choice will be maintained as far as it is not too much in contrast with the stimuli (the possible suitable choices constitute an equivalence class). Indeed, in order to have error correction we must have error, and we can have error only if the two systems, self and non–self, are independent. If they do not be, we could have no possible adaptation of the organism to its environment.

Any new stimulus represents more or less a negative feedback for the organism. Letting again aside the case in which the organism dies, each stimulus determine some partial correction (or at least the attempt at correcting) through which the organism try to assimilate the external environment to itself. However, if the net effect of each stimulus were only to partially modify the computational path and therefore the final response of the organism, we would again make use, though in a more sophisticated way, of the old idea according to which the output is a function of the input. However, this is not the only organism's reaction. It also tries to efface the effects of a shocking stimulus and therefore to come back to a stand–by situation. In this way, it tries to make reversible the effects of the stimulus. This is accomplished in two ways: By modifying the environment (through some external action that eventually has an indirect effect on the organism itself), and by incorporating the new representation in the net of the already tested representations. This behaviour is the internal counterpart of the environment's modification, and its aim is to reduce the "novelty" of the new representation. Without this latter action, we could not satisfy the Landauer–Bennett theorem, and therefore we could not assure the autarchy of the organism.

An evidence of this reversible anti–feedback can be found in higher organisms, especially in their dreaming activity.
Atlan [Atlan, 1972, Atlan, 1974] understood very well that, when dreaming, one recreates a state where all initial association that progressively had become forbidden is once again allowed. Obviously, this process can never be total, since, on the one hand, by effacing all mutual information with the environment one would never learn, and this with high unadaptive effects, and, on the other hand, because any shock leaves always some trace: this is the price to pay for the partial openess of the organism. Another evidence could come from recent studies

about the way rats fix they spatial memories during rest periods (see [Foster and Wilson, 2006]): They replay the sequence in a reverse order.

What happens in the majority of the cases is that, in its effort to eliminate the effects of an environmental feedback and therefore to restore its initial state, the organism integrates with more or less success this new stimulus in its previous representational net. In other words, we have a dynamical process of integration of two opposite forces, whose result is the reduction of distance not only between representation and stimulus but also between old representation and new response. For this reason, Hebb [Hebb, 1949, 111], quoting the words of Woodworth, says that all perceiving is *schema with correction*. Or, in the words of Walter Freeman [Freeman, 1995, 100] on higher brain activity, a "change constitutes a trajectory in cortical state space, which never return exactly to a prior state, but returns ... sufficiently close to the prior state that cortical output places a target of the transmission into the same basin of attraction as did the prior output". This dynamical, smoothing, integration process is what in higher organisms is called *interpretation* and is perhaps the biological basis of any intelligent behaviour. This distinction between stimulus, on the one hand, and its integration in a dynamical whole, *i.e.* its interpretation, on the other, has a neural basis, at least in mammals: It could be interpreted as a distinction between microscopic patterns of activity, which concern few neurons, are spatially and temporally localized, and are stimulus–locked, and macroscopic, global, spatial–temporal patterns, which are distributed over the entire sensory cortex involved and are directed to the meaning of the stimulus for the organism [Freeman, 1995, 59].

For all these reasons, we should correct the use of the term *random choice*. It is evident that with a certain (ontogenetic or phylogenetic) history of the organism, more and more regularities come out. Certain choices, if awarded, become habits. Moreover, when the organisms are growingly complex, a network of different sorts of regularities becomes possible, so that the choice is no longer random [Ellis, 2004]. To a certain extent it is neither for very rudimental organisms because already here there are a lot of different, at least physical, constraints. However, it remains true that any acquired regularity is always tested against a certain environment, and in this way the procedure remain inductive (open) as far as such a regularity can always be disproved, and to a certain extent will be too. If the stimulus represents a problem for the organism which requires some genuine new answer (a new choice) it would be a case of what Peirce [Peirce, 1886], [Peirce, 1878] called abduction [Auletta, 2005a]. In this process of optimization of the organism's response, when a specific reaction or action is reinforced and optimized more and more, it will become to a certain extent the automatized response of an organism to a class of (equivalent) stimuli. In this case, this response will be selected. In other words, selection is in general a process in which a rather indefinite response becomes more determined, and therefore also more stable. We have several evidences of such a behaviour for higher brains (see [Edelman, 1992] and [Edelman and Tononi, 2000]). This also means that, ascending in the evolutionary ladder, higher and higher organisms are necessarily open to an increasing variety of different stimuli. A bacterium is open to few stimuli. In other words, a high organism is less close than a unicellular one is. However, there are still mechanisms of control: they become rather indirect.

Obviously, the steps above indicated (computational process–choice–action–stimulus–new computational process) may not be necessarily executed in succession and by the organism as a whole. Actually, there can be partially autonomous subsystems, and many solutions are possible. This will however change nothing fundamental.

Resuming, an organism, at the most basic level, can be understood as an autonomous information–processing device that is in a second step confronted with an external stimulus. Its action tries to overcome to a certain extent the gulf between the result of its autarchic computation and the stimulus as well as between this result and the new response.

2

Biological Systems, Integrating Information and Entropic Fluxes

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Information acquiring can be considered a three–step or three–component process, in which a processor, a regulator, and a decider are involved. Biological systems are constituted through the integration of these three aspects. In particular, organisms consist of a protein feedback web involving a genetic processor, a regulating metabolic system, and a membrane, separating self and non–self. While a biological system may lack of metabolism, this is the allmarck of organism. These three subsystems can also be regarded as biological systems. The difference between a true organism and other forms of biological systems consists in their ability to integrate two opposite tendencies: the autonomy of the parts and the uniformity of the whole.

KEYWORDS: Infomation, entropy, cybernetics, processor, regulator, decider, genetic system, metabolism, membrane.

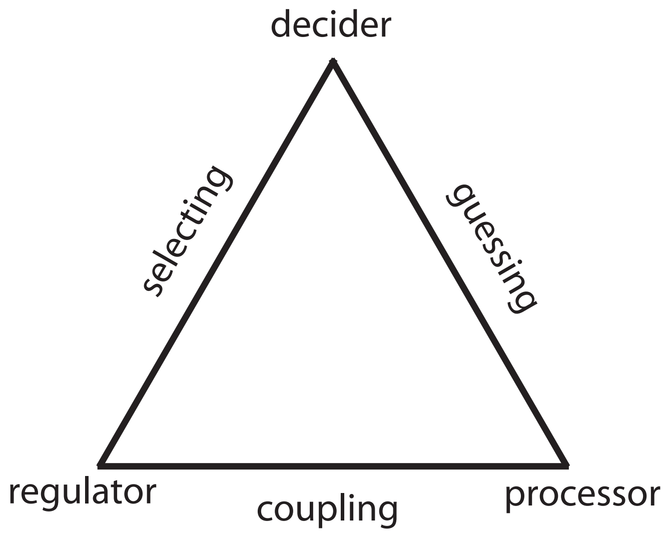

Figure 2.1: Processor–Regulator–Decider.

Introduction

This paper should be understood as an exercise in cybernetics applied to biological system. This means that I try to consider biological systems under a very specific point if view: As systems aiming at acquiring negentropy by controlling environmental information. This means essentially two things:

- This work presupposes molecular biology as the source of data and inputs. A system theory as that proposed here can only be a second–level teory that cannot substitute the fundamental theory.

- For this reason, no new scientific data are presented, but only differently interpreted. This interpretation can be in so far justified, if it provides new and interesting insights about already known problems.

By doing this, I take advantage of the way information is acquired at the physical level, and try to develop some generalizations that could also be applied to biological systems.

2.1 Information–Acquiring From a Physical Point of View

Physically speaking, there are three general aspects or steps in any information–acquisition process [see Fig. 2.1].

- Firstly, a *processor* is necessary, as a source of possible variety. The processor is the component that gives the input so that information can be acquired. It is not necessary that such a processor be random. What is necessary is that the algorithm producing the input be unknown. Otherwise, the acquired information would be valueless.

- The next component is represented by a *regulator*, that is, a system able to work as the interface between the processor and the final detection event. In other words, the regulator provides the necessary coupling, without which we could not speak of information acquiring. I shall return to this point, but let me add here that we never have direct access to any source of variation, we only access its (delayed) effects. This is already true from a relativistic point of view.

- Finally, we need a *decider*, that is, a device that, given a certain coupling, is able to give rise to a decision among a given set (in the simplest case, between two alternatives). In principle, this decision event can have no relation with the initial processor. It is only the coupling (second step) that guarantees that the final event says something about the state of the processor. In this way, we say that the decider has *selected* some information from among the different possibilities to which the processor gives rise.

I note here several things. First of all, there is no irreversibility in the whole process, apart from the final step of decision and selection. According to a theorem of Landauer [Landauer, 1961, Landauer, 1996] and Bennett [Bennett, 1973, Bennett, 1982], it is only information selection that gives rise to irreversibility in any information acquiring. For this reason, information processing can be completely reversible if there is no selection. It follows from this that the processor here can be considered as reversible. It is true that classical information theory [Shannon, 1948] started from the presupposition that information selection is at the source of the process, in terms of the choice of the specific message to be sent. However, this is a circular way to consider the problem: We know nothing about the source if not *through* a regulator (a channel, in information–theory terms), and anything we do know, we know it through a final decision. Why should we predate this final act of decision to an initial one? This would only deprive the whole information–acquiring process of any meaning. At present, this classical formulation can only work in situations where we have technological control over the classical source and over the receiver, but cannot provide an adequate general model of how information is acquired, especially with regard to quantum–mechanical and biological systems. As we shall see, in the latter case the involved systems never have a complete control on the informational sources, and for this reason their information acquiring is affected with some underdetermination, which in turn makes interpretational problems very relevant. Finally, I note that a similar remark was made by the father of cybernetics, Nobert Wiener, about classical systems. According to Wiener [Wiener, 1948], in all classical phenomena where considerations of probability and prediction enter into play, the answers become asymmetrical. One can, in fact, bring a system from the past into the present in such a way that one fixes certain quantities (this is called preparation) and assumes that the other quantities have known statistical distributions. One then observes the statistical distribution of results after a given time (that is, one performs a measurement on the system). This process cannot be reversed, since, in order to do so, one would have to select from the start a fair distribution of systems, which, with no intervention on our part, would end up within certain statistical limits, and thus find out what the antecedent conditions were after a given time. However, for a system starting from an unknown position to end up within a small statistical range is such a rare occurrence that it may be regarded as a miracle. Summing up, one can prepare a system in a certain way and then measure it, but not *vice versa*: In other words, selection comes after prepaation of the initial processor and after regulation. The reason for this is that the very act of selection always consists of an actual reduction from a space of possibilities.

Secondly, for these reasons, the whole information–acquiring process can be understood as a connection between the initial reversible information processing and a final irreversible acquiring event. This means that any process of information acquiring is also an entropic process, through and during which the three components become more disordered than before the process started. One of the biggest mistakes is to mix the concepts of entropy and information (or even to consider information as negentropy). In reality, we have information when there is neither too much order, nor too much disorder [Gatlin, 1972]. Moreover, pure quantum systems are in a zero–entropy state but show a potentially infinite amount of information and at least one bit of information can be obtained from them [Auletta, 2004b, Auletta, 2006].

In all physical processes these three components are separate, that is, each one is instantiated by a different physical system. Even complex systems behave in the same way. Let us take the simple example of Bénard cells. To a certain extent they show a capacity of endogenous self–regulation, provided there are long–term correlations that "coordinate" the motion of the single cells. Moreover, such a network is also able to act as a decider, provided each cell be either levorotatory or dextrorotatory. However, this network has no control at all on the processor, (the source of variety), that lies outside of the system and consists of a source of heat, which here is both an entropic mechanism (allowing the system reach more ordered configurations) and an informational one (able to generate certain specific couplings and decisions of the system). As we shall see later on, biological systems behave differently.

Some General Principles

Here and in the following sections, I try to consider biological systems as systems that emerge from a certain physical structure. In particular, they are characterized by their peculiar ability to integrate the above three components of information acquiring. This is possible if we take into account some general principles indicated by George Ellis so that a system can be considered as truly emergent [Ellis, 2005b, Ellis, 2005a]. They can be summarized as follows:

- There are modular hierarchical structures. These are necessary, since we cannot have the integration of different subsystems without some form of modularity, that is, of (relative) independence of the subsystems, as well as a form of hierarchy, that is, the submission of the systems to the structural and functional constraints of the whole. A modular hierarchy represents the decomposition of a complex problem in constituent parts and processes to handle these parts, each requiring less data and processing, as well as more restricted operations than does the whole.

- There are cybernetic systems, that is a system based on feedback circuits controlling information. In other words, systems in which the dynamics are governed by general formal constraints, and there is a strict connection between informational and entropic aspects. This is true for the whole as well as for the subsystems. Ellis in general stressed [Ellis, 2004] the importance of informational considerations when dealing with true emergent systems.

- There are the dynamics of adaptive modification and evolution. This integration is necessarily a dynamic one. I shall come back later to this point.

The Most Elementary Components

Let me first consider the most common and clear example of biological systems, the organism, whose most elementary form is the cell when dealing with unicellular organisms.
There are four different building blocks of organisms that are relatively common in our galaxy [De Duve, 2005, 6–9]: nitrogenous bases, sugars, fatty acids, and amino acids. it is not by chance that these compounds are the building blocks of organisms. I will not go as far as to say that any eventual extraterrestrial form of life must necessarily have these compounds exactly, but, it is my opinion that it should show an analogous structure. My reasons are the following:

- *Nitrogenous bases* are chemicals that are especially useful for storing, processing, and transferring information. Let us consider the case of RNA (as is well known, RNA was probably the main information processor in the first steps of life). RNA has four bases, cytosine (C), guanine (G), uracil (U), and adenine (A). Since in the template–directed RNA assembly, C is always connected with G, and U with A, we see that the four bases represent a double binary code that is particularly apt for the transferral of information by creating "negative" images of the original string.

- *Sugars* enter in all the metabolic processes of accumulation and transferral of free energy. Sugars are the principal food compound of many cells. In the course of glucose breakdown through a series of oxidations, energy (in the form of adenosine triphosphate: ATP) and reducing power (in the form of NADH) are saved and stored [Alberts, 1983, 43–45]. A chemical becomes oxidized when it loses electrons, and is reduced when it becomes electron–rich. The net result can be written

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy} \,. \qquad (2.1)$$

  Metabolism is the true regulator of an organism, since it is the mechanism which, thanks to the thermodynamic openness of the organism (i.e. the fact that the organism downloads entropy into the environment), allows for the preservation of the structural order of the organism, that is, of the structures that are built according to the genetic processor.

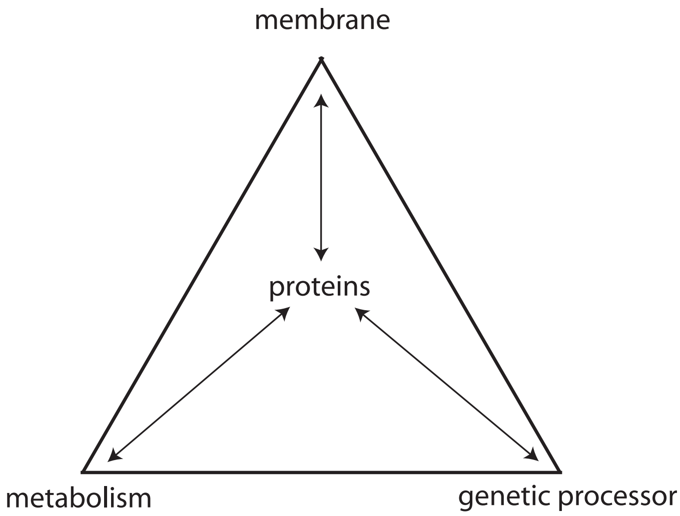

Figure 2.2: Schematic representation of the relationships between the different subsystems of an organism.

- *Fatty acids* pertain to the family of lipids and have originally constituted the compounds that give rise to the cellular membrane. It is the cellular membrane that sharply separates a self from a non–self, and therefore provides a first decider that selects what is allowed to enter into or leave a cell, eventually giving the metabolic system all that is necessary for its working.

- *Amino acids* are the building blocks of proteins. Proteins are often either considered as enzymes or valued for their specific functions. There is, however, a more general function that is of outmost importance: Proteins, toggether with RNA, guarantee all the fundamental passages in the organism's machinery, and constitute, in this way, the vehicles of all feedback interactions within the organism.

I wish to stress that what enters into the cell from the outside is treated at first in informational terms. Any electron that is acquired, for instance, is allowed to enter since it is previously selected as member of an equivalence class (for example, as a high–level electron). This is an informational procedure. The electron that has passed the test *acquires* an entropic meaning only when it enters the cell, since it is inserted into the metabolic web of the system. This also respects the fundamental cybernetic principle according to which cybernetic systems are entropically open and informationally closed [Ashby, 1956][Auletta, 2006]. Moreover, proteins as a whole do not constitute a system apart in the organism, but participate in any work done by the organism: As enzymes in the genetic and metabolic system, and as elements (mostly receptors) helping in the selection procedures of the membrane. Finally, I wish to stress the feedback role of proteins: they are produced according to the instructions of the genetic system and enter into the machinery of the metabolic system and the membrane. However, according to the needs of the latter two systems, they also react back into the genetic system by silencing and expressing parts of the genome [see Fig. 2.2].

Why are organisms built in this way? Because, it is only by integrating the informational and entropic aspect that they can control environmental information in order to acquire free energy for maintaining and improving their structure. As well as this, the intrinsic formal constraints are the mechanism that determines the dynamic of the organism. The need for free energy is obvious, due to thermodynamic considerations. However, an organism cannot have access to free energy (and pursuing in having that access), without the control of environmental information, especially considering that the environment can change in an unpredictable way. Aristotle already understood that organisms are built through a combination of a informational and metabolic dimensions.

Having integrated the processor inside the system (as a genetic system), the relations between the three systems are deeply modified, since the regulator is no longer coupled with an external unknown source of variations (even if, due to modularity, the genetic system is somehow unknown to the metabolic system). However, the whole is still dependent on external free energy and is therefore also reliant on external information (cellular transduction), so that the whole autarchy of an organism is, in reality, illusory. This is especially evident when considering the organism from an ontogenetic point of view, as we shall see.

I think that this way to consider organisms can be seen as a form of moderate functionalism. As a matter of fact, the different subsystems of an organism have a functional role, and, for this reason, we can assume that, on other planets, there could be forms of life that are characterized by other organic molecules, but playing the same role (for instance, they could present other forms of lipids or even other chemicals, having the function of a membrane, especially in environments without water). On the other hand, the metabolic system necessarily excercise a constraint on a pure functional architecture, since it connects the organism with its specific environment. This is another way to express the dependence of the organism on its environment.

Such a model can account for one of the main problems of present research in explaining the development of the first forms of life: the so–

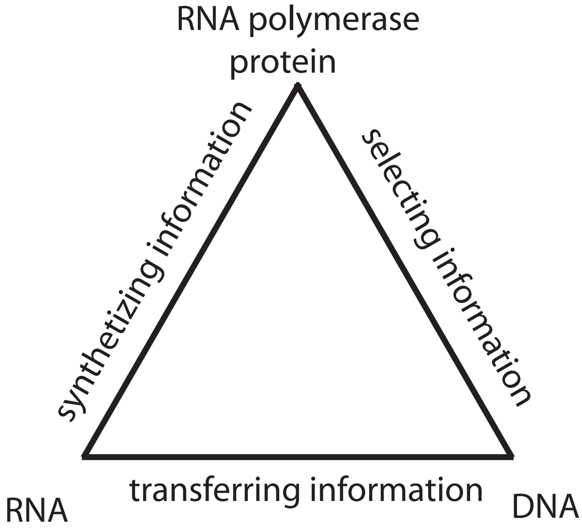

Figure 2.3: Genetic system. It is a true information–transferring system.

called premetabolic phase without RNA [De Duve, 2005, 149–51]. As a matter of fact, the integration process of the building blocks could have lasted a long time, during which proteins of the type known today, and RNA may not necessarily have been formed. More rudimentary and partial forms of these two organic compounds could have worked well, if integrated with sugars and membranes. One of the most commonly made errors is to assume that selection only begins with RNA, whereas that is firstly a consequence of the cell membrane, as I have already pointed out.

The Concept of Biological System

Organisms represent only the most common example of biological systems. In fact, each of the three systems constituting the organism (the genetic, metabolic, and membrane systems) also show general features that are similar to those of the organism. Let me define a *biological system* as any system that is able to integrate a processor, a regulator, and a decider. Let me first consider the genetic system of actual organisms. This can be very schematically depicted as follows:

- The DNA codes the information. This corresponds to a pure processing stage and the random mutation to message variations.
- The RNA (mRNA, tRNA, and rRNA) assures the necessary bridge (the regulator–step) so that this information can be used further.

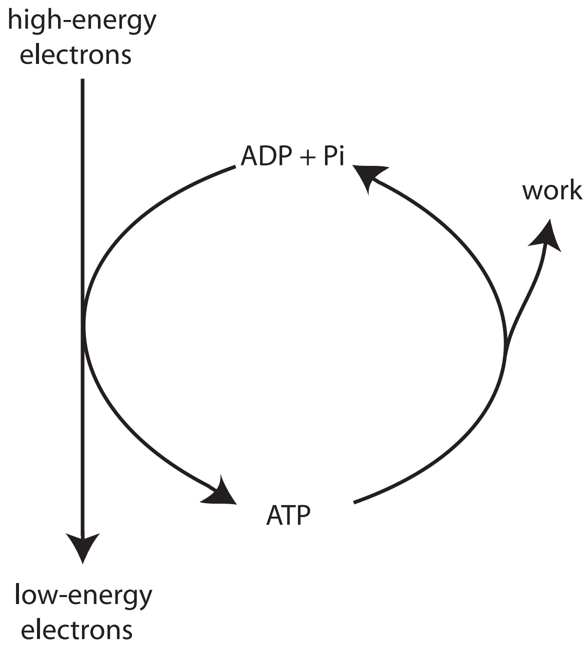

Figure 2.4: The use of high–levels electrons for building ATP. Inspired to [De Duve, 2005, 44].

- The outgoing protein together with the RNA polymerase is the feedback thats select which part of the DNA will continue to be active.

In this way, a single gene can act on many genes, activating and deactivating them. The whole system constitutes a feedback circle [see Fig. 2.3].

As well as this, the whole metabolic process can be considered as a three-system or three-step process:

- First of all, the energy is acquired through some molecular mechanism inside the membrane. One of the most important ways in which this is done is by capturing or producing electrons in excited state. High–energy electrons can be acquired through food for heterotrophic organisms or from mineral donors, in the case of chemotrophy, or can even be powered to excited levels thanks to sun energy in phototrophy (allowing, in this way, the same electrons to be used cyclically).
- Secondly, this energy is stored in the ATP molecules. As we have seen, high–energy electrons can somehow be acquired. By bringing

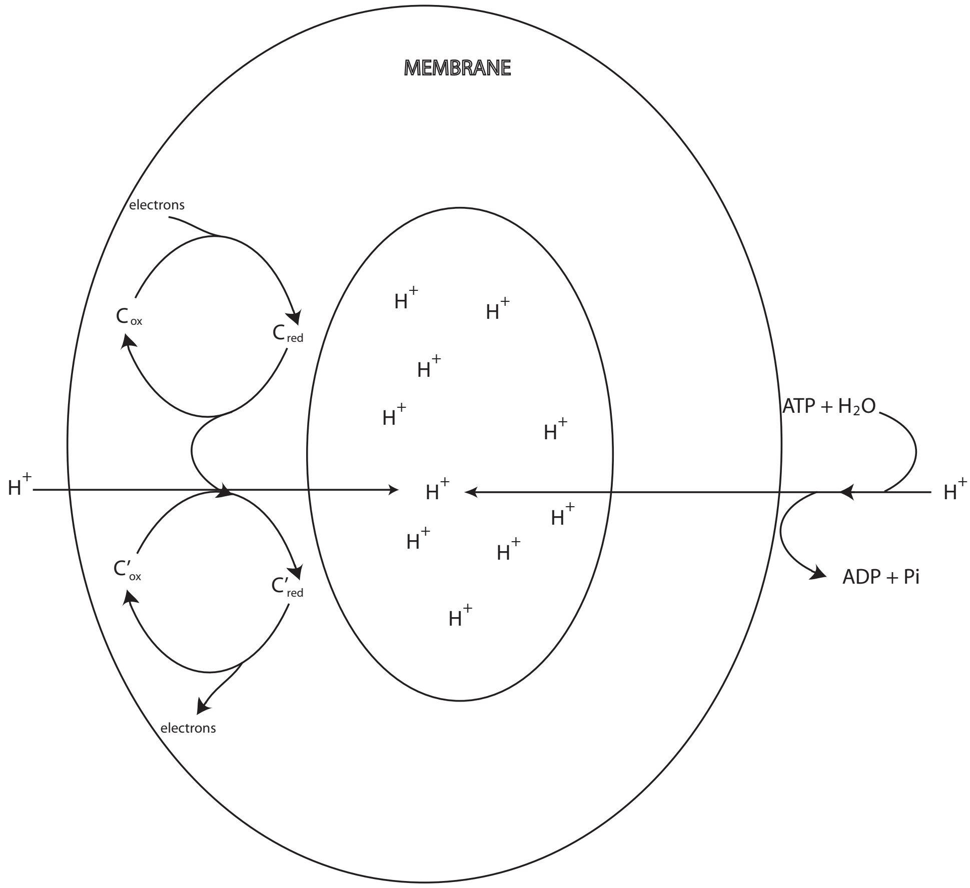

Figure 2.5: Mechanism of the protonmotive force. Inspired to [De Duve, 2005, 134].

them to ground state, one can use the differential energy for building ATP [see Fig. 2.4] [De Duve, 2005, 41–53]. Another mechanism that is much more widely used is represented by the protonmotive force [De Duve, 2005, 133–48]: two reversible proton (H^+) pumps are coupled, one driven by the transfer of electrons between two carriers and the other by ATP hydrolysis [see Fig. 2.5]. The first pump transfers protons making use of electrons that are given first to a carrier that becomes reduced, i.e. electron rich (C_{red}, which becomes thereafter the oxidized C_{ox}), and from this to another carrier C′, subject to an analogous procedure. The second pump transfers protons by the hydrolysis of ATP. When, as is often the case, the electron–driven pump builds a higher proton potential than the ATP–driven pump, the latter functions in

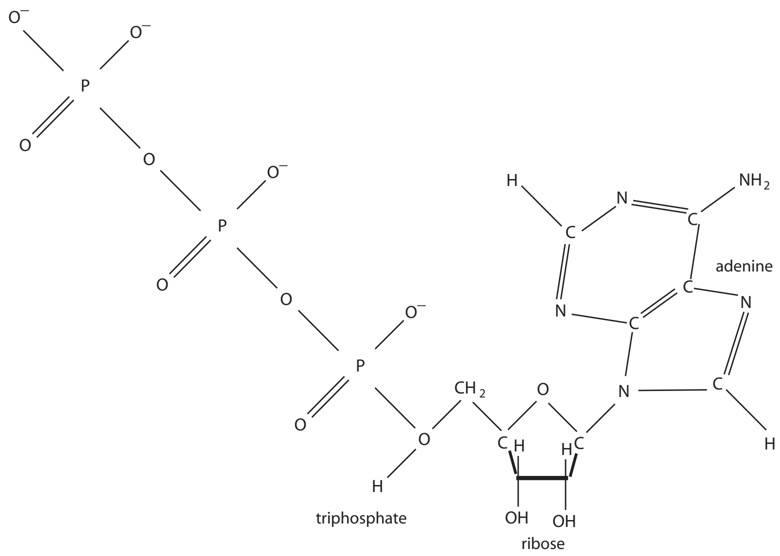

Figure 2.6: Adenosine triphosphate (ATP), the energy storing chemical is a combination of adenine and ribose (which give rise to adenosine) and of triphosphate.

reverse mode and synthesizes ATP [see Fig. 2.6].

- Finally, ATP is used for building polynucleotides, DNA, and RNA, selecting a specific destination from among many possible ones. In general, more complex molecules are built by dehydrating condensation, which, in order to work, is coupled with ATP hydrolysis (a process known as group transfer). ATP undergoes hydrolysis to release inorganic phosphate (P_i) and ADP (constituted by a diphosphate, adenine, and ribose) [see Fig. 2.7]:

$$\begin{aligned} &\text{triphosph.} - \text{adenine} - \text{ribose} \rightarrow \\ &\text{in. phosph.} + \text{diphosph.} - \text{adenine} - \text{ribose}. \end{aligned} \tag{2.2}$$

  This transformation provides energy for work and for chemical synthesis allowing for the storage of structural information. In this way, the organism, in acquiring free energy from the environment and discharging it in entropy, is able to build itself as a structured and ordered system.

It is true feedback, a self–increasing, circle [see Fig. 2.8]. The smallest organisms to present a metabolism are bacteria.

Let us now consider the membrane system. The membrane itself is a lipid bilayer constituted by the hydrophobic tails sticking together while

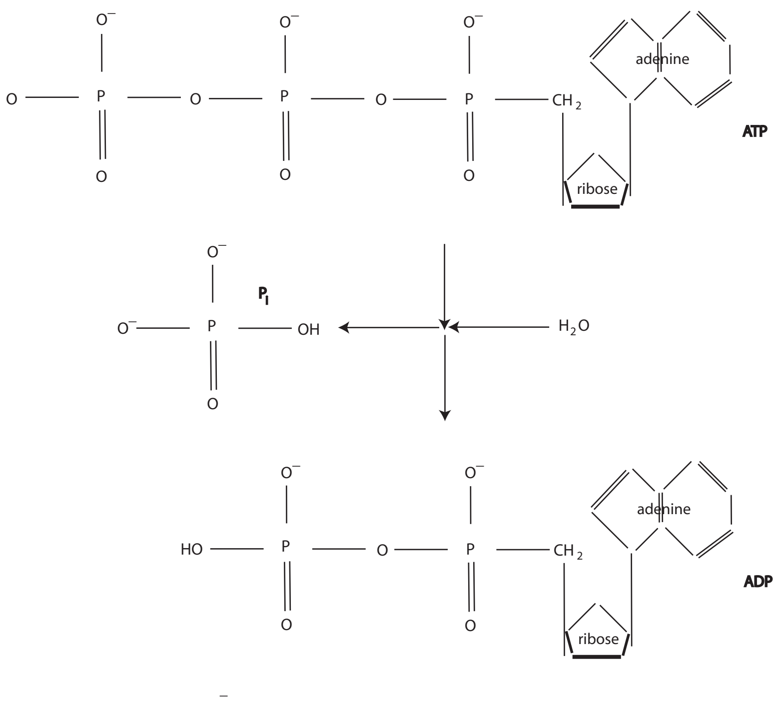

Figure 2.7: The chemical reaction producing ADP from ATP.

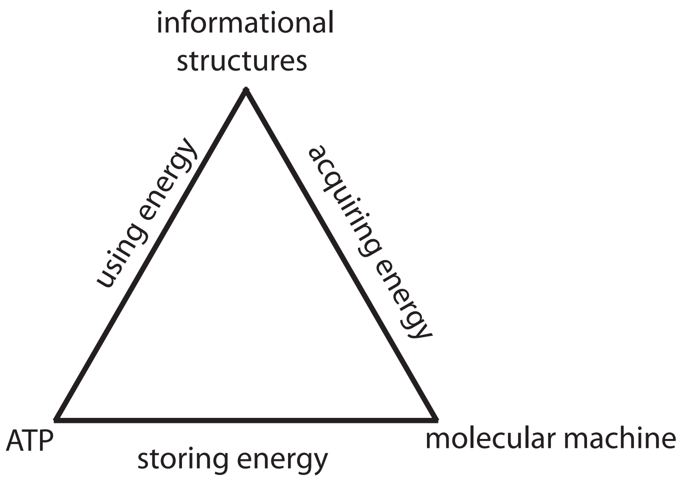

Figure 2.8: Metabolic circle. It is an energetic circle. The direction is here important and cannot be inverted: It runs clock–wise.

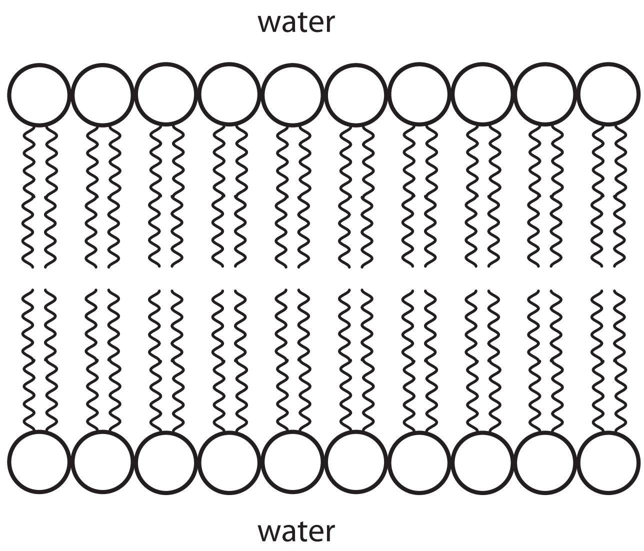

Figure 2.9: Membrane as a lipid bilayer.

the hydrophilic heads remain in contact with water [see Fig. 2.9]. Membranes spontaneously generate sack–like vesicles, that is, (relatively) closed systems. I have mentioned above that this system allows things to enter the cell from outside. Often, however, nothing enters, but an external input, with the help of additional proteins, gives rise to a cascade reaction *inside* the cell. In order that such a mechanism may work, it is first of all necessary that there be a receptor mechanism capable of identifying the external chemical. A comparator is then necessary in order to establish what kind of signal this chemical represents. In the most elementary cases, the receptor is tuned to specific signals, and therefore, is itself a comparator as well [see Fig. 2.10]. Finally, a molecular mechanism acts as a decider by giving rise to the appropriate reaction (in the most elementary case, acceptance or rejection). This is a true informational control system.

The concept of a biological system is of wide applicability. From the point of view of its reproduction, the organism may be regarded as a system consisting of a genotype (the processor), a rybotype (the coupling which ensures the necessary building blocks (proteins) according to genetic instructions), and a phenotype, (the final output selected) [Barbieri, 2003]. From an ontogenetic point of view, the phenotype is structured as a signal transducer (the processor), the metabolic system (the regulator), and a decision system. Here, dependence on the external environment is evident. Even if the organism tries to control it

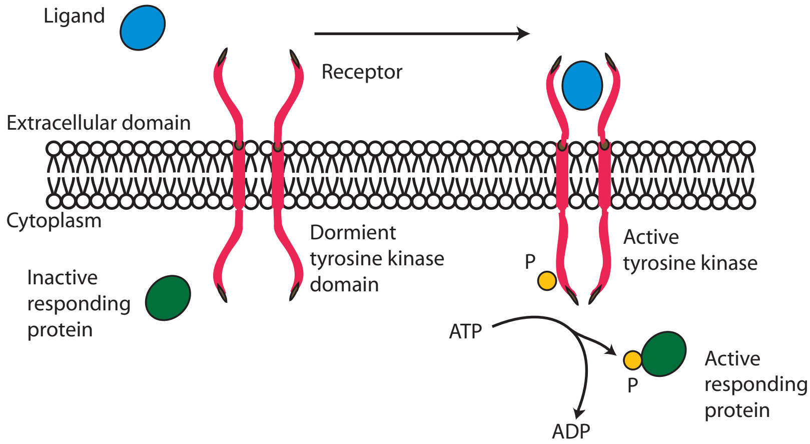

Figure 2.10: The basic mechanism of (paracrine) cell signalling. The external inducer give rise to an enzymatic activity. Usually, this is a kinase activity using ATP to phosophorylate specific kynase residues of cxertain proteins. Inspired to [Gilbert, 1991, 147]. See also [Wolpert, 2002, 299].

completely, it cannot entirely succeed.

2.2 Final Considerations

The structure of biological systems is a true fractal one, since there are no *a priori* limits in building biological systems as parts of previous ones or in collecting biological systems that already exist. An example of the latter is to be found in an ecosystem, in which the different species are the processor (source of variation), the ecological niche or niches, the regulator, (that is, the ground upon which different species encounter each other and somehow establish relations), and natural selection is the decider. In fact, it is probable that biological systems can be defined as scale free systems[1]. As such, population of different organisms are expected to follow general principles that might be the same as those defining the molecular network at the level of one organism. When looking at organisms from that perspective, individualistic and cooperation behaviors are those that are really in balance.

This explains an important aspect of life: biological systems at any level have the tendency to autarchy, that is, to become true organisms. If they are part of a bigger biological organism, this tendency manifests itself as an anarchic one, as happens, for example, with cancer cells. On the other hand, when the whole tries to become an organism, we have

[1] I owe this remark to Luc Jaeger.

the tendency to "totalitarism", as sometimes happens in human society or even with social insects. This tendency cannot succeed, however, as human society, for instance, cannot provide a true metabolism, but is dependent on the metabolism of its members. In general, a biological system can exist in dynamic equilibrium between these two opposite tendencies. This is the reason why biological systems are evolvable and developmentable, that is, are intrinsically dynamic. It is worth mentioning that even the so–called homeostasis, that is, the equilibrium of an organism, should be interpreted instead in dynamical terms as a homeorhesis [Waddington, 1974].

Obviously, as I have already remarked, even the autarchy of an organism is, to a certain extent, illusory, since it always relies on external free energy, and therefore on external sources of information.

From the above considerations, the fact also emerges that viruses are not biological systems, since although they are provided with at least some genetic material and a (non–lipidic) membrane, they have no regulatory mechanism (and this is also the reason why they proliferate *ad infinitum*). An interesting situation is when virus proliferation is kept under control. The case of the bacteriophage λ has been studied [Arber, 1983]. After certain steps, a species of "decision" is done: Either the bacteriophage pursue its reproduction idefinitely (this response is called lytic), and in this case the cell finally dies, or the virus reproduyction is kept under control trough production of the λ repressor cI which is in turn produced by promoters p_{RE} and p_{RM} (a response that is called lysogenic).

3

Life in the Universe: Big, Small, and Complex

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The Hospitable Universe

One of the curious features of the universe is the way in which it presents us with an environment which is superficially extremely hostile to the evolution of life. However, appearances can be deceptive. We know that the Universe is expanding and therefore its huge size is a consequence of its great age. Any universe which contains the building blocks of complexity must be old enough for stars to form and generate the elements on which chemical complexity is based. This requires elements heavier than those of hydrogen and helium which are formed into the first three minutes of the Big Bang. The heavier biochemical elements, like carbon, are then made from them by nuclear reactions in the stars. When stars die these biochemical elements are dispersed into space and ultimately find their way into planets and people. This process of nuclear alchemy is long and slow. It takes billions of year to run its course. Thus a universe that contains "observers" must be billions of years old and hence billions of light years in size. These are necessary conditions for life to be possible. Further consequences follow. The large size of a habitable universe ensures that it has a very low average density and so galaxies and stars are widely separated. Outposts of life are likely to be separated by vast astronomical distances, ensuring that development occurs in isolation from other outposts of life at least until technical knowledge is very sophisticated. The large amount of expansion also ensures that the universe is very cold. This, in turn, means that the night sky appears dark. There is too little energy density in the universe to make it bright. Thus universes that meet the necessary conditions for life are big and old, dark and cold. As we look more closely at the expansion of the Universe we find that it is delicately poised, expanding very close to the critical dividing line that separates universes which are expanding fast enough to overcome the pull of gravity and keep going forever from those which will ultimately reverse into a state of global contraction and head towards a cataclysmic Big Crunch at some finite time in the future. Indeed, so close are we to this critical divide that our observations cannot tell for sure what the long-range forecast holds. However, it is the very proximity of the expansion to the divide that is the big mystery: a priori it seems highly unlikely to arise by chance. Again, there is an anthropic aspect: universes that expand too fast are unable to aggregate material into galaxies and stars, so the building blocks of complex life cannot be made. By contrast, universes that expand too slowly end up collapsing before stars have time to form. Only universes that lie close to the critical divide can live long enough and expand gently enough for the stars and planets to form. It is no accident that we find ourselves living billions of years after the apparent beginning of the expansion of the Universe and witnessing a state of expansion that lies close to the critical divide.

Our Place in the Universe

We have a size that is a result of a balance between competing forces of Nature: the electromagnetic forces that determine the strengths of inter-molecular bonds and the force of gravity. These two natural forces determine the sizes of planets large enough to possess gaseous atmospheres yet small enough to allow solid structures to exist on their surfaces without being crushing to pieces by the surface gravitational field. They ensure that complex living things like ourselves are much larger than single molecules and much smaller than mountains and planets. Our size also determines how strong we are. We find that we are strong enough to break molecular bonds using rocks that are small enough to lift and we are big enough to use fire (there is a smallest possible flame that will burn in air – ants cannot use fire). If we were significantly smaller (and therefore weaker) we would not be able to do these things and the road to technological development might well be barred to us [Barrow, 1995] Our physical size therefore determines the range of dimensions over which we can manipulate and reorganise Nature for our own advantage. If we want to extend that domain of influence we must use artificial means. It is this quest to extend our ability to understand and manipulate Nature on superhuman and subhuman scales that creates a need for technical progress and a rough way of measuring it.

Types of Civilisation – macromanipulators

In the 1960s the idea of searching for extraterrestrial forms of intelligence (ETI) was a new and novel with many new forms of astronomical observation at its disposal. A Russian astrophysicist, Nicolai Kardashev [Kardashev, 1964, 217], proposed that we classify advanced ETIs as being of Type I, Type II, or Type III according to their technological abilities. These types of civilisation are distinguished by their capabilities in controlling and manipulating their environments as follows;

> **Type I** civilisations are capable of restructuring *planets* and altering their planetary environments. They can use the present energy equivalent of terrestrial civilisation for communications.
> **Type II** civilisations are capable of restructuring *solar systems*. They can use the present energy equivalent of the Sun for interstellar communications.
> **Type III** civilisations are capable of restructuring *galaxies*. They can signal across the entire visible universe using laws we know. They can use the present energy equivalent of the Milky Way Galaxy for interstellar communications.

The motivation for this classification was to estimate how much waste heat might be produced by activities on these scales so that one could decide whether it was detectable by astronomer and to determine whether a very distant Type III civilisation is easier to see than a nearby Type I. In this scheme of things we can see that we are certainly a Type I civilisation. We have altered the topography of the Earth's surface in many ways, building structures, and reclaiming land from the sea. We have altered the behaviour of the Earth's atmosphere by the production of unnatural gases and fluorocarbons. Our industrial activity may well have changed the temperature of the Earth. We have developed the capability to make major changes to the Earth either by design or by accident despite the fact that our exploration and exploitation of its interior structure has been relatively modest. So far it amounts to little more than the extraction of fossil fuels and minerals. We are nearly a low-level Type II civilisation. We could alter the evolution of some of the inner planets; for example by seeding Venus with primitive life forms and we could to divert incoming asteroids and comets from their orbits when they are in the outer parts of the solar system. Indeed, we may have to apply a Star Wars technology to do this in the future to safeguard ourselves from a catastrophic impact – there have been some alarmingly close near misses in the recent past. A fully-fledged Type II civilisation might be engaged in altering the chemical composition of their neighbouring star in some way (perhaps by diverting comets into it or altering its natural vibrations) in order to change the nature of their own biosphere. Type III civilisations are the stuff of science fiction stories and it is hard for us to conceive of manipulating matter over such enormous dimensions (perhaps by affecting the operation of cosmic radio jets – the largest coherent structures seen in the Universe) because of the huge periods of time that are necessary for signals to traverse these dimensions. In order for a civilisation to find such foresight advantageous they would have to have all possible local problems completely under control and possess very long (even unending) lifetimes. One could imagine that the concept of an individual lifetime might become irrelevant. With ultra-sophisticated computer technology capable of making complete "back-up" copies of minds individuals could overcome "death" in the usual sense. One could imagine different computers vying to provide you with the fullest regeneration, the one that loses the least experience, or even the one that removes some unwanted attributes or bad memories at the same time! In recent years there have been speculations about the far future of the Universe that speculate about even more advanced beings than those of Type III. In general we might imagine that hose of types IV, V, VI, etc... would be able to manipulate the structures in the Universe on larger and larger scales, encompassing groups of galaxies, clusters of galaxies, and superclusters of galaxies, ..., respectively. Ultimately, we could imagine a type Ω civilisation that could manipulate the entire universe (and even others). Interestingly, there has been a considerable amount of detailed speculation about what a type Ω civilisation might in principle be able to do and how it might do it.

Types of Civilisation – micromanipulators

Our extension of Kardashev's classification of civilisation "Types" is based upon their ability to manipulate the *large-scale* world around them (see [Barrow, 1998]). This is the hardest manipulation to conduct. It requires huge energy resources and is very difficult to reverse if things go wrong. In practice, we have found it much more effective to extend our ability to manipulate the world to small dimensions rather than to large ones. We might correspondingly extend our classification of technological civilisations downwards as Type -I, Type -II, etc... according to their ability to control smaller and smaller entities. These civilisations might be distinguished as follows:

> **Type -I** civilisations are capable of manipulating objects over the scale of themselves, building structures, mining, joining and breaking solids.
> **Type -II** civilisations are capable of manipulating genes and altering the development of living things, transplanting or replacing parts of themselves.
> **Type -III** civilisations are capable of manipulating molecules and molecular bonds and creating new materials.
> **Type -IV** civilisations are capable of manipulating individual atoms and creating nanotechnologies.
> **Type -V** civilisations are capable of manipulating the atomic nucleus and the nucleons that compose it.
> **Type -VI** civilisations are capable of manipulating the most elementary particles of matter (quarks and leptons).

....
culminating in...

> **Type -Ω** civilisations are capable of manipulating the structure of space and time.

Again, we can attempt to locate ourselves in this classification of technical capability. We have long been a Type -I civilisation and modern genetics has made us into a Type -II. The Human Genome Project is an international project to decode human genetic information with a view to identifying causes of various human traits and medical disorders. It marks the entry of biology into the "Big Science" league. It is apparent that we also possess Type -III abilities and routinely design materials to have particular properties and antibiotics to have special therapeutic properties. We have only just entered the Type -IV domain. We have recently developed an ability to move individual atoms and engineer surfaces at the level of single atoms. This forms the basis of the quest to develop nanotechnologies. It has long been a dream of scientists that they could construct microscopic machines – motors, valves, sensors and computers – down at the molecular scale. They could be implanted into larger structures where they would carry out their vital function invisibly, perhaps monitoring the heart of a cardiac patient or keeping vital arteries clear of blockages. Some devices of this sort already exist. They are likely to play an increasing role in everyday life in coming years.

We are struggling to maintain our status as a Type -V civilisation. We have been able to employ nuclear forces and sub-atomic particles in controlled ways to create sustained energy by nuclear fission, explosions by nuclear fission and fusion, but have failed to control all the by-products of these actions safely and reliably. Despite long and expensive investigations we have failed to produce viable sources of controlled energy from nuclear fusion reactions. Although this is a safer and cleaner source of nuclear power than is fission, it presents formidable problems of confining and controlling the plasma of interactants. So far, controlled power output has been possible only for very brief periods and is far more expensive than conventional energy sources. However, it is likely that these problems will one day be solved and these forms of energy will be necessary to replace waning supplies of fossil fuels. Another recent success of the Type -V sort has been the recent deliberate creation of a nucleus of antimatter (antihydrogen) at CERN in Geneva. If antimatter could be inexpensively produced it would give us a perfectly clean source of energy by the process of matter-antimatter annihilation (this will be familiar to watchers of *Star Trek* already).

We are not yet a Type -VI civilisation. We can produce elementary particles in high-energy collisions between protons and electrons and in other high-energy particle physics processes but we at the stage of watching the debris from those events to advance and consolidate our knowledge of the elementary particles themselves: to understand how many of them there are, their masses and lifetimes, and the qualities that identify them and limit the scope of their mutual interactions. As yet, we are unable to engineer these particles to produce complex aggregates with particular properties. So far we do not know whether such complexes can exist without being known aggregates like nucleons and mesons. Perhaps it will be possible to engineer combinations of elementary particles with special properties.

The ultimate technological achievements, which would be displayed by a Type -Ω civilisation would entail the ability to manipulate the nature of space and time at will. At present we can appreciate (theoretically) some of the ways in which this might be done but the conditions needed to implement such changes are far beyond the reach of our technology. Einstein taught us that moving clocks go slow and that clocks go slow in strong gravitational fields. We can observe these things occurring in high-energy physics experiments and in observations in the solar system and beyond. However, we are not in a position to create the circumstances in which these effects would be of technological benefit. A classic example, familiar to readers of science fiction stories, is the possibility of travelling in a short period of time to star systems many light years away by moving at a speed close to that of light. We also appreciate that there might be peculiar configurations of mass and energy which would permit time travel to occur or for local "wormholes" connections to be forged with parts of the Universe which appear (in terms of light travel time) to be enormously distant. The situation with possibilities of this sort is especially peculiar. We have a theory of gravitation, the general theory of relativity, which works with fantastic accuracy in every arena where it has been tested. We also appreciate some of its limitations; that is, we know that it must fail in particular very extreme circumstances (which we are in no danger of encountering or creating). This theory permits things like time travel to occur. But we do not know the full collection of restrictions that we have to impose upon the predictions of this theory in order to pick out those which are compatible with all the other properties of our Universe. Even when we have done that, we have to ask about the *likelihood* of something occurring. Time travel may be possible in principle and involve no violation of the laws of Nature yet have too low a probability of occurring (because of the very special circumstances required for it) for it ever to be witnessed in practice. For example, levitation is compatible with the known laws of physics in the sense that if all the molecules in my body just happen to drift upwards at the same moment I will leave the ground. There is a chance that this freak situation will occur; but that chance is so low (much less than once in the age of the universe) that we can be sure that any report of it happening is much more likely to be mistaken than it is to be true.

Types of Civilisation – complex manipulators

We should consider whether a third direction of manipulative achievement besides the realms of the very large and the very small: this is the realm of increasing complexity. Complex things are distinguished by the number of sub-components that they contain and the way in which they are linked together. Living systems are classic examples, so are societies, economies, weather systems, and large computers. None of these systems can be understood simply by learning what they are made of. We need to know how their components are linked together: this is makes them what they are. As the number of those connections increases so the potential for complex behaviour rises in sudden jumps. A Swiss physicist, Daniel Spreng, has schematised the interdependence of energy, time and information as a triangle [Spreng, 1978]. Any two of the three attributes (energy, E, time, t, and information, I) can be traded in for the other two. Any point in the triangle represents a particular mixture of the three ingredients needed to accomplish a given task. Near the corners of the triangle, we find three distinct situations: at E = 0 there is the thoughtful philosopher, who takes very long periods of time and lots of information to accomplish his task; the primitive human ancestor, perhaps, lives near I = 0, and uses lots of time and energy doing things, because he lacks information about labour-saving devices; thirdly, near t = 0, there is the world of the modern (and future) technological society where lots of energy and information are employed to gets things done very quickly, – the world of *Concord* and the Internet. In moving from one point in the triangle to another, we see what must be done to conserve energy. If we have lots of time then we do not need much information because we can indulge in an haphazard trial and error search. But if time is expensive, then we need to know the fastest way to do things and that requires lots of information. Alvin Weinberg has argued [Weinberg, 1980, 116] that this means that time is likely to become our most important resource. The value of energy and information is, ultimately, that it gives us more freedom to allocate our time. The acceleration of creative activity that we can expect in the future will take us along this third way, the saving of time by the expenditure of energy and the utilisation of information in greater and greater abundance. Our study of complex systems has also taught us that they often evolve by means of a sequence of erratic jumps, moving closer and closer to a state that is "critical" and maximally unpredictable. The classic paradigm for this type of complex self-organising behaviour is provided by the example of the sand pile, studied first by Per Bak [Bak, 1997].

Some Cosmological Speculations

Life must transcend planets and stars. The long-term forecast for ever-expanding and collapsing universes (or, equally, of expanding or contracting inflationary mini universes) means that life cannot survive into the indefinite future unless it ceases to be confined to planetary surfaces and to be based upon atomic chemistry of any sort. It must transcend these forms and make use of more elementary forms of information processing and information storage. Barrow and Tipler and Dyson have speculated about ways in which this might be implemented, using elementary particle states or electron spins to store binary information.

Can information processing last forever? Frank Tipler and the author showed [Barrow and Tipler, 1986] that it is possible for information processing to continue indefinitely into the future and there is no barrier to the extent of its coordination if the Universe possesses a certain type of overall structure if the universe is open or flat. It is interesting to note that we also discovered that if the Universe possesses a positive cosmological constant (as recent observations suggest) so that it is accelerating and will continue to accelerate into the future, then information processing will not continue indefinitely into the future [Barrow and Tipler, 1986, 668]: only a finite amount of information can be processed into the far future. “Life” must die out in such a Universe.

Will life get small or large? We have discussed how we might categorise civilisations by their ability to create or harness growing levels of complexity. This quest has some very specific aspects; for example, the development of computers of ever greater size and processing speed. This development can be seen to proceed at two levels: there is the increase in the power of individual machines by the optimisation of their internal network of interconnections; but there is also the growth in collective power by the networking of different computers. The Internet is the most familiar manifestation of this extension, but we could regard all non-local systems for information spread and retrieval, like the international telephone system, as examples of this general sort. From a minimalist perspective it is possible to classify all technological enterprises in terms of the amount of information needed to specify the structure completely and the rate at which that information needs to be changed in order for the system to change. In this way we see that a thermometer is simpler (that is, it requires less information for its complete specification) than a desk-top computer. The growth of a civilisation’s ability to store and process information has at least two quite different facets. On the one hand there needs to be a growing ability to deal with things that become large and complicated; but on the other there is pressure towards the compression of information storage into smaller and smaller volumes of space. This storage compression takes place within the context of some hardware and so the quest for nanotechnological progress is intimately linked to it. The pressure on natural resources, efficiency, and ecological preservation will drive technology down into the great unexplored realms of the nanoworld and below. Perhaps the most advanced life forms in the Universe are so small that they would be undetectable to our astronomical instruments. Maybe they are closer than we think?!

Connectivity – is anyone out there? The trend in the development of efficient information processing has been by connecting many small computers together. We have taken a leaf out of the design manual for our own brains to appreciate the importance of neural networking and the evolution of algorithms by a process of adaptation. On a cosmic timescale the continued development of intelligence may require further connectivity to occur over astronomical scales. Those connections must ultimately be made by extraterrestrial forms of intelligence.
For many years some astronomers have been searching for signals from extraterrestrials. None have been found. Why? If advanced extraterrestrials exist, where are they? Maybe long-lived technological civilisations are impossible. Perhaps they either exhaust their resources before they have the technology to leave their planet, run out of food, are killed off by disease or environmental disaster that follows from their technological progress. Or perhaps the discovery of the strong nuclear force of Nature leads inexorably to self destruction in nuclear war. It is a sombering thought that the human race could have been wiped out by several of these technical developments in the past (and may succumb to them in the future). We have just discussed some of the positive benefits of planetary impact by comets and asteroids. But there is a fine line between stimulation and annihilation. Maybe long-lived technological civilisations do not exist because of the certainty of catastrophic impacts over long periods of time. To avoid this fate they would need to have reached a level of sophistication that enabled them to protect their planet from impacts or to have migrated from being a simple planet-based life form. The problems have led to speculations that the most long-lived civilisations may necessarily become non-technological in character. However, this self denial would deprive them of the means to protect themselves from asteroidal impacts. Another interesting line of speculation is the psychological. Perhaps extraterrestrials don't call because they are not interested in talking to us. This might be because we are not interesting to them. If the Galaxy is teaming with millions of civilisations, of which we are yet another average example, then we may be treated rather as we would view another species of beetle. On the other hand, we may be

ignored because we are *too* interesting. If we are special then we may be left to evolve without interference so that we can provide important scientific data about a unique evolutionary development: in effect, we are being treated like a protected species in a Nature reserve.
Alternatively, we may be hearing nothing because we are too primitive. Extraterrestrial dialogue could be like membership of an elite club. Suppose that advanced extraterrestrial communication uses a form of technology that is far more advanced than we possess. It does this because it is both technically effective and exclusive. It keeps the club membership limited – limited to those who have passed a technological threshold that requires them to have mastered the great problems of ethical responsibility, aggression, disease, ecological disaster, that threaten all advanced technological civilisations. To admit a technological civilisation that had not passed these tests into the club of communicators where they would share the knowledge that each possessed would be disastrous to all its members.

Right-wing and left-wing futurology: competitors or co-operators. Some futurologists see the technological age as something that will ultimately be transcended by a race of cerebral beings who have learnt to counter their urge to expand their territory and to manipulate Nature. They will be co-operators rather than competitors. Only by halting technological advance will they be able to live within the bounds of their planetary system and remain in some measure of equilibrium with their environment . It is often predicted that these advanced beings would have to possess altruistic and ethical principles: these are seen as necessary conditions for any ultra long-lived civilisation to persist. This scenario is quite consistent with the expectation that one consequence of ultra-advanced technology would likely be the enormous (or even indefinite) extension of individual lifetimes. This would lead to a slow-down in the evolution of diversity and would result in a form of self-imposed equilibrium without progress of the Faustian sort. This view is common amongst enthusiasts for extraterrestrial intelligence and those engaged actively in the search for it. This is not surprising. Since the greatest possible pay-off from such searches would be contact with extremely advanced intelligent life-forms it is important to convince oneself that their intentions towards us would be entirely honourable. Biologists have some reason to believe that altruism is a strategy that is optimal in fairly general circumstances and altruistic behaviour can be selected for without the need to impose it by adopting ethical codes. If one believed otherwise then our best strategy would be the development of effective smoke screens to hide the evidence of

our own existence rather than to broadcast it over the interstellar radio spectrum.
Papagiannis believes that the civilisations “that manage to overcome their innate tendencies toward continuous material growth and replace them with non-material goals will be the ones to survive the crisis. As a result the entire Galaxy in a cosmically short period will become populated by stable, highly ethical and spiritual civilisations.” [Papagiannis, 1984, 309]
The alternative “right-wing” view sees survival becoming harder and harder for long-lived civilisations. They may have had to regenerate their civilisations on several occasions following disasters of war or impacts by comets and asteroids on their planets. Their future is one dominated by competition between computers [Moravec, 1988]; [Stapleton, 1968].
These possible scenarios are similar to the end-states of biological competitions in either a “rat-race” or an “evolutionarily stable strategy” (that is an equilibrium in which any competitor which deviated from this strategy would be worse off).

Highly evolved intelligence leads to unpredictable by-products. Somehow one expects that the more advanced an intelligence becomes so the more extensive, non-linear, and unpredictable will be the by-products of that intelligence. When we assess those aspects of human consciousness that we find especially valuable they very often appear to be by-products of an ability evolved for mere survivability or fecundity. Our highly developed artistic abilities, musical appreciation, and abstract science are all examples of such sophisticated by-products. When we talk about human intelligence it is often just these abilities that we have in mind, yet they have not been directly selected for in the evolutionary process. This is what makes the future of living beings so unpredictable. In fact, one can show that their behaviour is not only difficult to predict, it is unpredictable *in principle* [Popper, 1950, 117 and 173]; [Mackay, 1974, 110]; [Barrow, 1998, 232-237].

4

Emergence in the Real World

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Physics and chemistry underlie the nature of all the world around us, including human brains. Consequently some suggest that in causal terms, physics is all there is. However we live in an environment dominated by objects embodying the outcomes of intentional design (buildings, computers, teaspoons). The present-day subject of physics has nothing to say about the intentionality resulting in existence of such objects, even though this intentionality is clearly causally effective. This paper examines the claim that the underlying physics uniquely causally determines what happens, even though we can't predict the outcome. It suggests that what occurs is the contextual emergence of complexity: the higher levels in the hierarchy of complexity have autonomous causal powers, functionally independent of lower-level processes. This is possible because top-down causation takes place as well as bottom-up action, with higher-level contexts determining the outcome of lower level functioning and even modifying the nature of lower level constituents. Stored information plays a key role, resulting in non-linear dynamics that is non-local in space and time. Brain functioning is causally affected by abstractions such as the value of money and the theory of the laser. These are realised as brain states

in individuals, but are not equivalent to them. Consequently physics per se can't causally determine the outcome of human creativity, rather it creates the possibility space allowing human intelligence to function autonomously.

Physics and the Everyday World

Physics is the model of what a successful science should be. It provides the base for the all other physical sciences and biology because all objects we see around us, including ourselves, are made of the same fundamental particles whose interactions are governed by the fundamental forces identified and investigated by physics.

The extraordinarily successful reductionist approach of present day physics is based on the concept of an isolated system. Experiments carried out on such systems enable the physicist to isolate and understand the fundamental causal elements underlying physical reality. However no real physical or biological system is in fact isolated, either physically or historically; biological systems are open systems [Campbell, 1991], and in the real world, context matters as much as laws [Bishop, 2005]. The physics approach tends to ignore three crucial features that enable the emergence of biological complexity out of the underlying physical substratum [Ellis, 2006a]: namely, top-down action in the hierarchy of complexity, which affects both the operational context and nature of constituent parts; the causal efficacy of goals and information; and the origin of biological structure and information through evolutionary adaptation. These features enable the causal efficacy of emergent biological order, described by phenomenological laws of behaviour at each level of the hierarchy. What occurs is *contextual emergence* of complexity, crucial to the nature of the everyday world around us. The higher-level laws emerge out of the underlying physics, which establishes a possibility landscape [Ellis, 2004] delineating possible ways of creating biological functionality [Conway Morris, 2003], [Vogel, 1998]. However the higher level properties are largely independent of that underlying physics [Anderson, 2005], which is why biologists don't need to study quantum field theory, the standard model of particle physics, or nuclear physics.

In this article I look at aspects of the properties of emergence, and consider some of its consequences for our understanding of causality. The key take-home message is that the *higher levels in the hierarchy of complexity have real autonomous causal powers, functionally indepen-*

dent of lower-level processes. The underlying physics both enables and constrains what is possible at the higher levels, creating the possibility space of outcomes, but does not enable us to actually predict events in the everyday world around us. Physics per se does not even causally determine the specific outcome of the higher level functioning. I will demonstrate this by considering the relation between initial data in the very early universe and the existence and functioning at the present time of truly complex systems that embody purposive action (such as ourselves).

Complexity and Hierarchical Structure

Hierarchy

True complexity, with the emergence of higher levels of order and meaning, including life, occurs in *modular hierarchical structures* [Simon, 1962], [Booch, 1994]. They are *structured* in that their physical nature reflects a precise ordering as in very large intricate networks, for example the micro-connections in a VLSI computer chip or amongst neurons in the human brain. Such systems are not complex merely because they are complicated; "order" means organization, in contrast to randomness or disorder. They are *hierarchical* in that layers of emergent order and complexity build up on each other, with physics underlying chemistry, chemistry underlying biochemistry, and so on [Campbell, 1991], [Peacocke, 1990]. Figure 1 gives a simplified representation of the hierarchy; for a more detailed description see [Morowitz, 2002]. Each level is described in terms of concepts relevant to that level of structure (particle physics deals with quarks and gluons, chemistry with atoms and molecules, and so on), so a different descriptive language applies at each level[1]. Thus we can talk of different levels of meaning embodied in the same complex structure.

This is the phenomenon of *emergent order*, with the higher levels displaying new properties not evident at the lower levels. As expressed by Campbell [Campbell, 1991],

> "*With each upward step in the hierarchy of biological order, novel properties emerge that were not present at the simpler levels of organisation. These emergent properties arise from interactions between the components ... Unique properties of*

[1] A clear example of such a language hierarchy occurs in digital computers [Tannebaum, 1990].

> *organized matter arise from how the parts are arranged and interact ... [consequently] we cannot fully explain a higher level of organisation by breaking it down to its parts*".

One can't even describe the higher levels in terms of lower level language. Effective theories such as the Fermi theory of weak interactions, the gas laws, and Ohm's law give a phenomenological understanding of behaviour at higher levels [Hartmann, 2001]. The higher levels are more complex and less predictable than the lower levels: we have reliable phenomenological laws describing behaviour at the levels of physics and chemistry, but not at the levels of psychology and sociology. Thus this is a hierarchy of complexity.

Complex structures are *modular* in that each level is made up of more or less independent modules whose structure and behaviour can be studied in their own right - molecules are made of atoms, living bodies are made of cells, and so on; one can study atoms and living cells in their own right, and then see how they fit together to make molecules and bodies. There is no clear theoretical definition of true complexity, but for practical purposes it is a system that involves more than say 10^6 such interacting active components. A modular hierarchy represents a decomposition of a complex problem into constituent parts and processes to handle those constituent parts, each requiring less data and processing and more restricted operations than the problem as a whole [Booch, 1994]. This is clear for example in complex computer programs, which may have 15 million lines of code; they are only understandable because they are written in a modular way with numerous separate subroutines that can be each understood on their own. The success of hierarchical structuring depends both on implementing modules to handle lower-level processes, and on integration of these modules into a higher-level structure. Modules can be modified and adapted to fulfil new functions, enabling great flexibility as complex structures adapt to a changing environment.

Higher-Level Variables and Coarse Graining

The essential key to understanding emergent properties is *correct choice of higher-level concepts and associated variables.* It is not possible to understand or explain the emergent properties in terms of the lower level concepts and variables alone. Superfluidity, for example, cannot be deduced from the lower level properties of the quantum fluid alone [Laughlin, 2000, Laughlin, 2005]. The Hodgkin-Huxley equations governing membrane current propagation in neurons in the brain similarly do not follow from lower level properties alone:

> "*The equations are not 'ordinary laws of physics' (as Schrödinger pointed out) but 'new laws' that emerge at the hierarchical level of the axon to govern the dynamics of nerve impulses. One cannot derive these new laws from physics and chemistry because they depend on the detailed organisation of the intrinsic proteins that mediate sodium and potassium current across the membrane and upon the geometric structures of the nerve fibers*" [Scott, 1995, 52-53].

In each case one can indeed derive physical arguments for the higher-level properties, but only by introducing suitable higher-level concepts not implied by the underlying physics.

Many higher level variables are functions of aggregated lower level variables, determined by them but by their nature abstracting important properties of the hierarchy that are otherwise hidden. These higher-level variables are thus *coarse-grained versions of the lower-level variables*: they represent the system as seen from the higher-level view with many lower-level (fine-grained) details averaged over. For example, gas pressure and density are macro-variables result from averaging over relevant micro-variables: numbers, masses, and momenta of constituent molecules in a given volume. A current flowing in a wire is represented at a macro-level by a number of amperes, representing the aggregate amount of charge flowing in the wire, but at the micro-level is described by a distribution of electrons in the wire. Stating the number of amperes flowing provides a useful coarse-grained description of the micro-situation. Together with the related resistance and energy variables, this choice gives phenomenological understanding of the higher-level behaviour (the flow of current in a wire is related to the voltage and resistance). Thus higher level variables can be considered as active agents in determining the causal outcome (a higher voltage produces a higher current, giving more heat, etc).
The loss of lower level information associated with this coarse graining (if we only know the current is 10 amperes, we don't know the detailed electron distribution) is the source of entropy – many lower level states correspond to the same higher-level state [Penrose, 1989, 310-314]. Consequently the higher level states are relatively insensitive to many details of the lower level state of the system.

Some causally effective higher-level concepts and variables, however, are associated with collective effects that appear to be more than just coarse-grainings or aggregates. Their very nature depends on the higher level structure. Furthermore some higher-level variables are not physical variables at all, but rather are *of a mental or abstract nature*, for example feelings of hate, the concept of a country, the concept of an electromagnetic field, differential and integral calculus, and the theory of the laser. They are themselves hierarchically structured, and are causally effective because they are key elements in the functioning of the human mind in either a social or technological context

Bottom-up and Top-down Action

The first key issue underlying complex emergent behaviour is the occurrence of both bottom-up and top-down action in the hierarchy of structure and causation.

Bottom-up Action

What happens at each higher level is based on causal functioning at the level below, hence what happens at the highest level is based on physical functioning at the bottom-most level. When I move my arm, it moves because many millions of electrons attract many millions of protons in my muscles, as described by Maxwell's equations. Thus microphysics underlies macro effects. The successive levels of order entail chemistry being based on physics, material science on physics and chemistry, geology on material science, and so on. This is the profound basis for physicalist worldviews:

> "*The underlying physical laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known, and the difficulty is only that the exact application of these laws leads to equations much too complicated to be soluble*" [Dirac, 1929, 714].

Top-down Action

However additionally, higher-level structure together with the system's environment (which sets boundary conditions for physical variables) enable higher-level variables to influence lower-level variables by setting the context in which they function. This leads to *downward causation* [Campbell, 1974] and *contextual emergence* [Bishop, 2005]. For example, when I move my arm, it moves because I have decided to move it, thus in effect my intention is causally effective in terms of instructing many millions of electrons and protons what to do. This is possible because the detailed physical structuring of the hierarchical system, in this case the physiology of the nervous system, provides the context in which the lower level causality functions.

The Effects of Top-down Action

Top-down action affects the nature of causality significantly, because *inter-level feedback loops become possible* (Figure 2). Additionally, *top-down (contextual) effects modify the properties of the constitutive elements at the lower levels.* For example, "the emergence of the novel entity water obliges the two component elements to a relatedness (chemical bonding and the corresponding mixing of the electronic orbitals) that profoundly affects the properties of both hydrogen and oxygen" [Luisi, 2002]. A dramatic example is the properties of neutrons, which together with protons form atomic nuclei: they are unstable with a half-life of eleven minutes when unbound, but stable with a half life of billions of years when bound into a nucleus. This plays a key role in underlying the stability of chemical elements, thus allowing the existence of life. Crucial to daily physics is the fact that electrons interact strongly with photons (via Thomson scattering) when free, but only weakly when bound into atoms; the interaction of matter and light is completely different when electrons are free compared with when they are incorporated in ordinary matter. The resulting transition from strong to weak coupling as matter and radiation cool in the early universe underlies the decoupling of matter and radiation, allowing the start of structure formation by gravitational attraction. A change of context results in a major difference in the physical behaviour of constituent elements, with a different physical understanding of the interactions (Thomson scattering gets replaced by spectral theory) described by quite different equations. At a much higher level of complexity, an individual human mind is crucially affected by the society in which it develops [Berger and Luckmann, 1967]; for example the language it uses as a basis for understanding is culturally determined. Indeed you cannot understand a mind in isolation, because the specific form of the modern mind has been determined largely by culture [Donald, 2001], [Richerson and Boyd, 2005].

At the largest scales, the cosmological context influences the nature of local physics through top-down action [Ellis, 2002]. At the foundations, classical physics emerges from quantum physics through an irreversible process of quantum decoherence, providing the basis for the very existence of independent component elements. This occurs through interactions with the environment that result from holistic features of quantum theory [Joos, 1998], [Zurek, 2003]. Thus *complex systems are not just conglomerates of unchanged elementary constituents; rather by their specific structuring, at all scales they profoundly affect the nature of the constituents out of which they are made.*

Examples of top-down Action

Top-down action is prevalent in the real physical world and in biology. I will illustrate this with a series of examples.

Interaction potentials. Potentials in the Schrödinger equation, or in the action for the system, represent the summed effects of other particles and forces, and hence are the way the nature of both simple and complex structures can be described (from a particle in a box to the detailed structure of a computer or a set of brain connections). These potentials describe the summed interactions between microstates, enabling top-down effects by creating an ordered structure underlying causal relations (electrons flow in specific wires connecting specific components, neurons connect to specific other neurons, etc.). Additionally one may have external potentials representing top-down effects from the environment on the system, for example the gravitational field due to a massive planet alters the motions of particles in a laboratory located on the surface of the planet.

Nucleosynthesis and structure creation in the early universe. The rates of nuclear interactions depend on the density and temperature of the interaction medium. The nuclear reactions that take place in the early universe, and hence the elements produced in nucleosynthesis then, therefore depend on the rate of expansion of the universe, determined by macroscopic cosmological variables. Hence the resulting nuclear abundances can be used to determine the average density of baryons in the universe a key cosmological parameter [Dodelson, 2003]. Similarly the linearised equations for cosmological structure formation depend on the averaged quantities in the background universe (its density and expansion rate, for example), which therefore determine the nature of the perturbation solutions and the resulting formation of structure in the expanding universe.

Evolution. Top-down action is central to two main themes of molecular biology: first, the *development of DNA codings* (the particular sequence of base pairs in the DNA) occurs through an evolutionary process which results in adaptation of an organism to its ecological niche [Campbell, 1974, Campbell, 1991]. As a specific example: a polar bear *Ursus maritimus* has genes for white fur in order to adapt to the polar environment, whereas a black bear *Ursus americanus* has genes for black fur in order to be adapted to the North American forest. The detailed DNA coding differs in the two cases because of the different environments in which the respective animals live. This is a classic case of top-down action from the environment to detailed biological microstructure - through the process of evolutionary adaptation, the environment (along with other causal factors) fixes the specific DNA coding. *There is no way you could predict or explain this coding on the basis of biochemistry or microphysics alone.*

Biological development. A second main theme of molecular biology is the reading of DNA in the cells in an organism during the processes of biological development. This is not a mechanistic process, but is context dependent all the way down [Fox Keller, 2000]. The central process of developmental biology, whereby positional information determines which genes get switched on and which do not in each cell, so determining their developmental fate, is a top-down process from the developing organism to the cell, based on the existence of gradients of positional indicators (morphogens) in the body [Gilbert, 1991], [Wolpert, 2002]. Thus the crucial developmental mechanism determining the type of each cell in the body is controlled in an explicitly top-down way. The key issue in development is not so much which genes occur in DNA, but rather which of the genes in the DNA get switched on where and when. Context controls the outcome.

Mind on the world. When a human being has a plan in mind (say a proposal for a bridge being built) and this is implemented, then enormous numbers of micro-particles (comprising the protons, neutrons, and electrons in the sand, concrete bricks, etc. that become the bridge) are moved around as a consequence of this plan and in conformity with it. Thus in the real world, the detailed micro-configurations of many objects (which electrons and protons go where) is determined by the plans humans have for what will happen, and the way they implement them. An example is the effect of human actions on the earth's atmosphere, moving many micro-particles (specifically, CFC's) around, thereby affecting the global climate.

***The effectiveness of rationality*:** Concepts such as the plans for a Jumbo Jet, worked out on a rational basis through a process of computer aided design, are not the same as any specific brain states, for they can be represented in many different ways (in words, writing, diagrams, in computer memories associated with CAD programs, etc). Rather they are an abstract entity: an equivalence class of such representations. They are causally effective because they determine the nature of physical objects in the world: they guide the manufacture of material objects.

***The effectiveness of emotions*:** Emotions both influence immediate behaviour in obvious ways ("She acted in anger", etc.), and also underlie brain development and intellect. Higher levels of order and meaning are developed through the basic emotions setting up implicit goals in the developing brain, which then guide neural development by providing the value system for the processes of neural Darwinism [Ellis and Toronchuk, 2005]. In this way basic emotions can be causally effective. Just as in the case of qualia such as perceived colour or pain, these are not the same as brain states, although they are associated with them.

***The effectiveness of social constructions*:** Socially devised rules and regulations (housing policy, health care systems, etc.) govern social relations and many resulting actions. The rules of football and of chess affect what happens in physical terms when the corresponding games are played. The effectiveness of money, which can cause physical change in the world such as the construction of buildings, is based in social agreement. These are abstract variables based in social interaction over an extended period of time, and are neither the same as individual brain states, nor equivalent to an aggregate of current values of lower level variables (although they may be represented by, and causally effective through, such states and variables).

Causal models of the real world will be incomplete unless they include these various effects. Multiple top-down action from the mind co-ordinates action at lower levels in the body in a coherent way, and so gives the mind its causal effectiveness. Because of this the causal hierarchy bifurcates (see Figure 4.3). The left hand side, representing causation in the natural world, does not involve goal choices. The right hand side, representing causation involving humans, is to do with choice of goals that lead to actions.

Ethics is the subject shaping goals at the highest level of the causal hierarchy, which deal with life purpose and appropriate choice of lower-level goals. By determining the nature of lower level goals chosen, and thence the nature of resulting actions, ethics is a set of abstract principles that are causally effective in the real physical world, indeed they crucially determine what happens. For example the jails in a country will contain physical apparatus such as a gallows or an electric chair only if the ethics of that country allow the imposition of the death penalty; they will not exist in countries where this is not regarded as acceptable. Wars will be waged or not depending on ethical stances; large-scale physical devastation of the earth will result if thermonuclear war takes place.

Summary

Overall, top-down action is how context affects what happens. It is like setting a set of hardware of software switches for an electronic apparatus which then decide the mode of operation of that machine at that time, giving different possible sets of outputs in response to the same input (for example determining if a computer will operate in word-processing, spread-sheet, or image processing more). Quite different modes of action occur depending on the context, even thought the underlying physical operations are identical in all cases.

Feedback Control sSystems and Information

The second key issue underlying complex emergent behaviour (already alluded to above) is the existence of a hierarchy of goals that are causally effective, because they are the key to the functioning of feedback control systems and enable information driven interactions.

Information, Feedback Control, and the Causal Efficacy of Goals

The central feature of organised action is *feedback control*, whereby setting of goals results in specific actions taking place that aim to achieve those goals [Ashby, 1956], [Beer, 1966, Beer, 1972]. A comparator compares the system state with the goals, and sends an error message to the system controller if needed to correct the state by making it a better approximation to the goals (Figure 4). Examples are controlling the heat of a shower, the direction of an automobile, the speed of an engine, or the running of an organisation.

A key feature is that such systems damp out the effects of fluctuating initial data: they are designed precisely to give the same output whatever initial state occurs (within the limited domain that the system is designed to handle). *The system output is determined by its goals rather than the initial data.* Thus the way physical effects lead to resultant behaviour ("output") is quite different when feedback systems are involved. The usual understanding of how physics works is summarised as follows:

(*Physical laws, equations of state, boundary conditions, initial data*) ⟶ Output

or taking for granted the context of the physical laws, equations of state, and boundary conditions, simply

(*Initial data*) ⟶ Output

In the case of a structured system with feedback control, this becomes quite different:

(*Physical laws, structure, boundary conditions, goals*) ⟶ Output

or taking for granted the context of the physical laws, physical structure, and boundary conditions, simply

(*Goals*) ⟶ Output.

Rather then giving an output depending on the initial state or boundary conditions, the system is designed precisely to give the same output whatever the initial state. You are ill if your body temperature differs significantly from 98.4F; many bodily systems function to keep the temperature at that value irrespective of outside conditions. Thus in order to predict the behaviour of goal-seeking systems, you need to know the goals, not the ambient conditions.

Because truly complex systems are necessarily hierarchically structured, their behaviour is determined by a *control hierarchy.* This occurs for example in fluid convection [Bishop, 2005], in individual human lives, and in society at large. Thus if I plan to build a factory I have to employ builders; they have to order components from manufacturers; the manufacturers must plan a production schedule; etc. Managing large systems is essentially an exercise in hierarchical control management [Roberts, 1981] and the human nervous system is a classic example of hierarchical decentralised control [Beer, 1972].

The Role of Goals and Information

The series of goals in a feedback control system are clearly causally effective. They embody information about the system's desired behaviour or responses. Knowledge about goals and the environment can be exchanged between agents by means of information transfer, and can lead to changes in the goals and hence in behaviour. Here, *pragmatic information*[2] is related to *abstract patterns* and *has a purpose* - to cause some specific change [Roederer, 2005]. *Information driven interactions* involve control by pattern-dependent operations rather than physically-based responses:

> "*A specific one-to-one correspondence is established between a spatial or temporal feature or pattern in system A and a specific change triggered in system B. This correspondence depends only on the presence of the pattern in question ... information is the agent that embodies the above described correspondence and is always there for a purpose ... the much-sought boundary between physical and biological phenomena can be found wherever a force-driven complex interaction becomes information driven by natural means*" [Roederer, 2005, 111-120].

Goals are not the same as material states, although they will be represented by material states and become effective through such representations (e.g. the desired temperature of water may be set on a thermostat, and represented to the user on a dial; the thermostat setting is itself a representation of the desired goal). A complete causal description of such systems must necessarily take such goals into account.

The crucial issue now is what determines the goals: where do they come from? Two major cases need to be distinguished.

Homeostasis: In-built Goals

There are numerous systems in all living cells, plants, and animals that automatically, without conscious guidance, maintain homeostasis - they keep the structures in equilibrium through multiple feedback loops that fight intruders (the immune system), control energy and material flows,

[2]Information has syntactic, semantic, and pragmatic aspects [Küppers, 1990, 31-56].

breathing, the function of the heart, etc. [Milsum, 1996]. They are effected through numerous enzymes, anti-bodies, and regulatory circuits of all kinds, for example those that maintain body temperature and blood pressure. They have developed in the course of time through the adaptive processes of evolution, and so are historically determined in particular environmental context, and are unaffected by individual history. Their existence is genetically determined, having been inbuilt through the process of Darwinian evolution (selection processes acting on random variations), and embodies practical solutions to optimisation problems faced by our animal and human ancestors. It does not follow from physics *per se*.

Not only are the feedback control systems themselves emergent systems, but also *the implied goals are emergent properties that guide numerous physical, chemical, and biochemical interactions in a teleological way*. They embody biological information guiding the development of plants and animals; for example the information in DNA, embodied in the specific sequence of base pairs, guides the process of protein synthesis in cells through controlling construction of a specific sequence of amino acids according to the genetic code, thus determining cell type and function. A series of feedback control mechanisms check that this information is correctly read when proteins are made and correctly replicated when DNA is duplicated. Thus biological information is causally effective through feedback control processes.

Goal-seeking: Socially and Mentally Determined Goals

However at higher levels in humans and animals, important new features come into play: there are now individual behavioural goals that are not genetically determined. Many of them are conveyed to individuals through a variety of social mechanisms by which they become internalised [Berger and Luckmann, 1967, Chapter 5]; others are learnt or consciously chosen. *It is in the choice and implementation of such goals that explicit information processing comes into play.* Information arrives from the senses and is analysed, sorted, and either discarded or stored in long term and short term memory, from whence they help guide future behaviour. Thus humans are *information gathering and utilising systems* [Hartle, 2003]. This is a highly non-linear process, which is non-local in space (because of senses such as vision and hearing, and technologies such as television and cell phones) and in time (because of memory effects in the brain, and preservation of information through writing and electronic recording). It is enabled by the pattern recognition capacities of the brain, enabling *information driven interactions* [Roederer, 2005]. Conscious and unconscious processing of this information sets up the goal hierarchy, which then controls purposeful action in individual and social life. They may or may not be explicitly formulated.

At the highest level, the process of analysis and understanding is driven by the power of symbolic abstraction, codified into language embodying both syntax and semantics [Deacon, 1997]. This underpins other social creations such as specialised roles in society and the monetary system, and higher-level abstractions such as mathematics, physical theories, philosophy, and legal systems all encoded in symbolic systems. They gain their meaning in the context of a shared world-view and cognitive framework that is imparted to each individual by the society in which they live through many social processes. Together these form a culture that crucially affects human behaviour and alters the course of human history. Indeed the true situation is that there is gene-culture co-evolution [Richerson and Boyd, 2005].

Non-physical entities such as the theory of thermodynamics and technology policy underlie the development and use of technology that enables transformation of the environment. They are created and maintained through social interaction and teaching, and are codified in books and perhaps legislation. While they may be represented and understood in individual brains, their existence is not contained in any individual brain and they certainly are not equivalent to brain states (electromagnetic theory for example is not the same as any individual's brain state). Rather the latter serve as just one of many possible forms of embodiment of these features (they are also represented in books, journals, CDs, computer memory banks, diagrams, the spoken word, etc).

Thus concepts can exist in their own right, independent of any specific realisation or representation they may be given in specific circumstances. Indeed *they can be transformed between many such different representations precisely because they are independent of any single one of them.* They are often socially agreed to, and exist in the context of a world of social constructions [Ellis, 2004].

The Nature of Causality and Explanation

The key point about causality in this context is that simultaneous multiple causality (inter-level, as well as within each level) is always in operation in complex systems. Thus one can have a top-down system explanation as well as bottom-up and same level explanations, *all three being simultaneously applicable.*

Reductionist analysis "explains" the properties of the machine by analysing its behaviour in terms of the functioning of its component parts (the lower levels of structure). Systems thinking tries to understand the properties of the interconnected complex whole [Churchman, 1968], [Flood and Carson, 1988], and "explains" the behaviour or properties of an entity by determining its role or function within the higher levels of structure [Ackoff, 1999]. For example, the question: "Why is an aircraft flying?" can be answered

- *In bottom up terms*: it flies because air molecules impinge against the wing with slower moving molecules below creating a higher pressure as against that due to faster moving molecules above, leading to a pressure difference described by Bernoulli's law, this counteracts gravity, etc.;

- In terms of *same-level explanation*: it flies because the pilot is flying it, after a major process of training and testing that developed the necessary skills, and she is doing so because the airline's timetable dictates that there will be a flight today at 16h35 from London to Berlin, as worked out by the airline executives on the basis of need and carrying capacity at this time of year;

- In terms of *top-down explanation*: it flies because it is designed to fly! This was done by a team of engineers working in a historical context of the development of metallurgy, combustion, lubrication, aeronautics, machine tools, computer aided design, etc., all needed to make this possible, and in an economic context of a society with a transportation need and complex industrial organisations able to mobilise all the necessary resources for design and manufacture. A brick does not fly because it was not designed to fly.

These are all simultaneously true non-trivial explanations; *the plane would not be flying if they were not all true at the same time.* The higher-level explanations involving goal choices rely on the existence of the lower level explanations involving physical mechanisms in order that they can succeed, but are clearly of a quite different nature than the lower level ones, and are certainly not reducible to them nor dependent on their specific nature. The bottom-up kind of explanation would not apply to a specific context if the higher-level explanations, the result of human intentions, had not created a situation that made it relevant.

Physics and Higher Level Causality

Physical Determinism

The claim made by determinism is *physical causal completeness*: *for any specific physical system, including human minds, physical laws alone give a unique outcome for each set of initial data*. In effect the claim is that quantum uncertainty – which of course we know is present – only affects micro-events but is not important as regards macro-events, for which a classically determinist view is both valid and sufficient to fully determine outcomes.

To see the improbability of this claim, one can contemplate what is required from this viewpoint when placed in its proper cosmic context (see Figure 4.5). The implication is that the particles that existed at the time of decoupling of the Cosmic Background Radiation in the early universe [Silk, 2001], [Dodelson, 2003] just happened to be placed so precisely as to make it inevitable that fourteen billion years later, human beings would exist and Crick and Watson would discover DNA, Townes would conceive of the laser, Witten would develop M-theory.

In my view, this is absurd. It is inconceivable that truly random quantum fluctuations in the inflationary era – the supposed source of later emergent structure [Dodelson, 2003] – can have had implicitly coded in them the future inevitability of the Mona Lisa, Nelson's victory at Trafalgar, Einstein's 1905 theory of relativity. Such later creations of the mind are clearly not random, on the contrary they exhibit high levels of order embodying sophisticated understandings of painting, military tactics, and physics respectively, which cannot possibly have directly arisen from random initial data. This proposal simply does not account for the origin of such higher-level order.

The basic issue raised here is: *what is the relationship between the cosmic initial data and the higher level order that exists later*? To explore this further, consider the logically possible options (Figure 4.6). The *first option* is that the order we see today is only apparent, but is not real; in fact there is no order underlying what we see around us today. I include this only for completeness, because some people claim to support this view. However in my view it is simply incoherent; we could not be engaged in rational discussion if it were true. The order we see around us includes societies, languages, cities, communication systems, books, manufactured objects, communally shared theories of physics, and so on. Its existence is plainly manifest.

The *second option* is that there was in fact a high level of order imbedded in the data at the time of decoupling leading to the order we see today, and originating in quantum fluctuations at the end of inflation that also had high levels of order imbedded in their structure. What I mean by "order" in this context is this: the high-level order that exists today has arisen out of the data for the visible universe that is present at the time of decoupling of matter and radiation, being the time development of that data when evolved according to the applicable dynamical laws. Then rerunning the whole with the same data will lead to identical outcomes, and small alterations of positions and velocities of particles there make a corresponding real difference in the results today. For example, if some of those particles are perturbed a bit Einstein would have developed the theory of relativity in 1906 instead of 1905, or would have written the famous equation $E{=}ma^2$ instead of $E{=}mc^2$. This kind of effect would occur if details of what happens today depend linearly on small enough initial perturbations. Various nonlinearities, e.g. existence of chaotic systems [Hao, 1984], [Thompson and Stewart, 1987] or the "catastrophies" characterised by Rene Thom [Thom, 1989] can lead to much larger final changes for a small change in initial data: human beings would not exist, for example, so there would be no human theories to contemplate. Thus the dependence on initial data may be extremely fine-tuned, and the later order that occurs (such as the specific words in Einstein's 1905 paper) is both an outcome specifically determined by the initial data in the context of the relevant dynamics, and would not have occurred in the specific form it did with marginally different initial data. Then it is reasonable to say that the resultant higher-order meanings that emerge later were latent or implicit in that data. This is what I mean by saying that order was imbedded in the initial fluctuations. This is not to say I take a "blueprint" view of how things work in relation to the initial data: one the contrary, the way the initial value theorems of physics work is more like a "recipe" than a "blueprint". Within this context, physics by itself cannot plausibly create higher-level meanings out of random initial data: there is nothing in any of the physics "uniqueness and existence" theorems that even hints at such a possibility.

Consequently if physical determinism were true, Einstein's 1905 paper on Special Relativity would be hidden in the perturbations at the time of decoupling in the early universe. If this were the case, it could have happened either by pure chance, or because some agency placed that ordered structure there. The "chance" option is so unlikely that it is reasonable to discount it - "chance" initial data would have to fully account for every apparently rational human action in the past, present, and future. The "agency" option denies the standard assumption that quantum fluctuations are random, and will be rejected out of hand by most physicists because it introduces a causal element from outside physical theory into the early universe.

But in any case, consideration of quantum uncertainty shows this option won't work. We could not fine-tune the initial data precisely so as to give the desired higher level outputs today, because the required degree of precise predictability relating the initial data to the present-day outcomes is not present. Furthermore, there is growing evidence of an important role of indeterminacy in brain and behaviour, from the neuronal to the social level [Glimcher, 2005]. Physics and biology must take indeterminism seriously.

Physical Indeterminism: Randomness and Attractors

It is a profound feature of physics that there is quantum uncertainty at the micro level: what happens is determined by deterministic equations for the evolution of the wave function, plus a measurement process whose outcome is only determined in a probabilistic way [Penrose, 1989, Penrose, 2004]. Physics determines the chances of outcomes, but not a specific outcome. The inability to precisely predict the future on a micro scale leads to a rapidly diverging set of outcomes as we consider the result of more and more quantum measurement processes as time progresses. Quantum theory denies the possibility of determining a single physical outcome from given initial data, and the longer the time involved, the greater is this uncertainty. In many circumstances statistical physics results will apply on a large scale and this uncertainty will wash out. However there are other circumstances where this is not the case, for example where there is a photomultiplier or a CCD providing digital images from single photons that can then be amplified digitally or electronically. One case where this is significant in biology is the effects of quantum fluctuations on DNA, where the biological developmental process acts as the amplifier [Percival, 1991]. This result alone already shows that in the biological context quantum uncertainty is crucial, in that it determines a whole family of possible outcomes from given initial data rather than a single biological outcome.

Two competing effects complicate the situation. Firstly *there are attractors in the physical possibility space* - a key aspect of the context in which this all occurs. For example self-gravitating dark matter structures have a universal velocity distribution function which is an attractor in the possibility space. This kind of structure will almost inevitably occur irrespective of the details of the initial data within a wide basin of attraction in parameter space, with only a few macroscopic parameters dependent on the initial conditions (e.g. [Hansen, 2005]). Thus *to a large degree it is not the initial data that determines these outcomes, but the structure of possibility space.* It can be argued that the nature of the possibility landscape, based in the underlying physics and chemistry as functioning in this context, strongly restricts the possible physical mechanisms whereby the functionality of life can be achieved, so that while the variety of life may be very different on other planets in the visible universe, the underlying biochemical structures enabling their functioning may be very similar [Conway Morris, 2003]. The inevitable outworkings of the underlying physical laws then almost inevitably lead to a specific class of structures (stars and star clusters, for example, as well as basically similar living systems), with only detailed parameters determined by the initial conditions; initial data is only weakly relevant provided it lies in the basin of attraction, indeed memory of much of the initial data is lost due to friction and dissipation effects.

However, the higher order meanings embodied in the mind and resultant physical objects produced through mental activity are not this kind. The parameter space for combinations of letters on a page does not contain such physically determined attractors; a vast number of combinations of letters are allowed by the printing process which are not words in any known language. No purely physical channelling structure will lead to a sequence of letters and punctuation marks that make sense. The possibility space of all written text does not specifically encode mathematical theorems or physics theories – these certainly exist in this space, as they have indeed been written down, but as small islands of meaning in a vast sea of meaningless text, and no purely physics based process has any way of telling which is which. *Thus if a purely physical evolution determines what happens, these meanings will not be probable outcomes of the way the possibility space is structured.*

Secondly *chaotic systems exist in significant biological contexts*, for example the physical processes governing the weather on earth, so the initial data can never be known precisely enough to determine a specific outcome. This can have a major impact on the evolution of life because climate and weather do indeed seriously affect animal survival probabilities. While one can still contemplate that the system is "in principle" deterministic despite this "in practice" unknown outcome, that is only possible when we ignore quantum fluctuations. In fact quantum randomness will lead to random fluctuations in the data in the classical limit, ensuring that effective classical initial data cannot even in principle be prescribed to the required level of accuracy to obtain a specific outcome [Bishop and Kronz, 1999]. Thus although chaos is damped in quantum systems, chaotic systems can act as amplifiers of the uncertainty introduced by quantum processes into the classical limit, where they result in a spectrum of Gaussian fluctuations (the inflationary universe theory is an example of this process: see [Dodelson, 2003]. Similar effects occur close to the edges in parameter space characterizing catastrophes: a very small change in initial data leads to very large changes in outcome. Causation of precise outcomes by purely physical processes from specific initial data in the very early universe is not even theoretically possible when such systems are significant, because at its foundations physics is stochastic.

Physical Indeterminism and Biology: Adaptive Selection

It is far more likely that the *third option* in Figure 6 is the true situation: the later higher level outcome were not the consequences of specific aspects of the initial data, even though they arose out of them. Conditions at the time of decoupling of the Cosmic Background Radiation in the early universe fourteen billion years ago were such as to lead to life and ultimately minds that are autonomously effective, able to create higher-level order without any fine dependence on initial data. The higher level understandings in the mind were not specifically implied by the initial data in the early universe, neither were their physical outcomes such as television sets and cellphones.

This is possible if there is a large-scale context that is causally channelling the development of fluctuations "in the right direction" for them to eventually contribute to the existence of minds creating such things as the Mona Lisa. This channelling is provided by the combination of the nature of the underlying possibility landscape, and the developing order accumulating through Darwinian evolutionary processes, selecting between variations provided by chance effects on the large scale and quantum uncertainty on the small scale. Random variation followed by selection is a powerful mechanism that can accumulate biological order and information related to specific purposes [Roederer, 2005]. At the micro level, it can be characterized as the *Molecular-Darwinistic approach* [Küppers, 1990]. According to Glimcher [Glimcher, 2005], it is apparent in neuroscience and behaviour:

> "*The theory of games makes it clear that an organism with the ability to produce apparently indeterminate patterns of behavior would have a selective advantage over an animal that lacked this ability ... at the level of action potential generation, cortical neurons could be described as essentially stochastic the evidence that we have today suggests that membrane voltage can be influenced by quantum level events, like the random movement of individual calcium ions the vertebrate nervous system is sensitive to the actions of single quantum particles. At the lowest levels of perceptual threshold, the quantum dynamics of photons, more than anything else, governs whether or not a human observer sees a light*".

A key feature here is that while this process of variation and selection proceeds in a physical way, it also involves abstract patterns that are not physical phenomena for selection processes operating in biological systems develop in such a way as to recognise abstract patterns, which then become part of the causal processes in operation. Thus

> "*material learning processes can in principle solve the problem of the origin of information .. meaningful information can indeed arise from a meaningless initial sequence as a result of random variation and selection.. natural selection defines a gradient of evolution, not a detailed path, for reaching the (nearest) maximum*" [Küppers, 1990, 83-86].

Overall, this mechanism is the way top-down action shapes the lower level components to fulfil their higher level roles. The selection process utilizes higher level information about the environment which may or may not correspond to coarse-grained variables to shape the micro-level outcomes.

Part of the developing order is the human brain itself. Its structure relates higher-level variables to coarse-grained lower-level variables, with feedback control implementing higher-level goals in a teleonomic way. Both features damp out the effects of lower level statistical fluctuations and quantum uncertainty, replacing them with a tendency to achieve

specific goals. Additionally it is influenced by higher order variables, allowing autonomous functioning of the mind so as to handle high-level abstract concepts represented by language and internal images. All of these set the context in which the non-linear local operations of the mind interpret what is happening.
Non-material features such as Platonic mathematics [Penrose, 2004] can affect the operations of the mind. Additionally mental constructs such as theories of physics, based in and reflecting well the material nature of the world around us but still constructions of the mind in a social context, are included in a. It is through the variables p that the non-material feature of qualia are causally effective. The mind gets to be structured in this way through the kind of adaptive process outlined here, both in terms of its historical evolutionary emergence, and in terms of developmental processes acting in each individual brain.
Physics provides the necessary conditions for the existence of such higher-level phenomena, but not the sufficient conditions to determine the resulting behaviour. These are affected by causally relevant higher-level variables which attain meaning and causal effectiveness at their own level. A mind's behaviour is determined by its interaction with other minds [Donald, 2001] and the higher-level entities that in fact shape its outcomes, including abstractions such as the value of money, the rules of chess, local social customs, and socially accepted ethical values. These kinds of concepts are causally effective but are not physical variables – they all lie outside the conceptual domain of physics, and have only come into existence as emergent entities within the past few thousand years. They are not explicitly encoded in the physical initial data. The key point is that human understandings and intentions are causally effective in terms of changing conditions in the physical world, but are outside the domain of physics.

Emergence and Causal Closure

Some of the physical cases considered above refer to ***Weak Emergence***: this is when in principle a system may be fully described by the microscopic degrees of freedom alone, but in practice one would rarely choose to do so, both because the attempt is not illuminating, and because one will usually be unable to do so in reality. However the more interesting cases are those where I have claimed we encounter ***strong emergence***:*even in principle*, micro-level laws fail to fully determine outcomes of complex systems, so that causal closure is achieved only by appealing to downward causation [Bishop, 2005]. But this claim is clearly in trouble if the system is already causally closed at the micro-level, as is the case with most model systems considered by physicists. For higher levels to be causally efficacious over lower levels, there has to be some causal slack at the lower levels, otherwise the lower levels would be causally over-determined. Where does the causal slack lie? Four key features are relevant.

Firstly, in considering specific physical and biological systems, it lies partly in the *openness of the system: new information can enter across the boundary and affect local outcomes*. For example, cosmic rays may enter the solar system and alter the genetic heritage of individual humans; alteration in solar radiation can cause climate change on earth; telephone calls from afar convey vital information that changes how we act. Context is crucial to physical outcomes for local systems, and is embodied in both structural and boundary conditions; for example this is crucial in structuring the brain. New influences, not present in the system to start with, help shape its future.

However this does not solve the issue on the largest scales: one can always consider a bigger system, including more and more of the universe within its boundaries, until at the cosmological scale we consider all that exists and there is no longer a possibility of such boundary effects occurring.

Secondly, it lies in *quantum indeterminism* (random outcomes of microphysical effects), *combined with adaptive selection*, as explained above: random outcomes at the micro-level allow variation at the macro-level, which then leads to selection at the micro-level but based in macro-level properties and meaning. Quantum uncertainty provides a repertoire of variant systems that are then subject to processes of Darwinian section, based on higher level qualities of the overall system. For this to work, one needs amplifying mechanisms in order to attain macroscopic variation from quantum fluctuations. This was explored above: some physical systems (such as photomultipliers and the human eye) amplify quantum effects to a macroscopic scale; some classically chaotic systems can amplify fluctuations in initial data that are of quantum origin[3]; some of the effects captured in Thom's catastrophe theory allow large amplification of microscopic changes; and some molecular biology processes (for example involving replication of mutated molecules) act as such amplifiers.

[3] When chaotic systems are quantized, their chaotic behaviour normally goes away, but that is not the context envisaged here.

At a profound level the universe is indeterministic, allowing the needed causal slack. By itself that does not lead to emergence of higher level order; but it does allow this on the one hand through existence of attractors in possibility space, and on the other through the process of adaptive selection.

The third key feature is that *top-down action changes the nature of the lower elements so that they are fitted to higher level purpose.* There is not just a situation of invariant lower level elements obeying physical laws; rather we have the nature of lower level elements being changed so that the way they obey physical laws fulfils higher level purposes. One should distinguish here different timescales of operation: physical functioning takes place on short timescales, while this adaptation occurs both on developmental (medium term) timescales and on evolutionary (very long term) timescales. It is through such processes that the efficacy of goals and abstract concepts can be implemented, with the efficacy of initial data being replaced by the causal power of inbuilt and chosen goals. Thus *the nature of micro causation is changed by these top-down processes*, profoundly altering the mechanistic view of how things work.

Finally, *one can argue that free will plays an autonomous causal role not determined by physics*; if so, that would be an important part of the causality in operation. This is a clearly controversial territory, and some deny that free will truly exists. However we should recognize that the enterprise of science itself does not make sense if our minds cannot rationally choose between alternative theories on the basis of the available data, which is indeed the situation if one takes seriously the bottom-up mechanistic view that the mind simply dances to the commands of its constituent electrons and protons, algorithmically following the imperatives of Maxwell's equations and quantum physics. *A reasoning mind able to make rational choices is a prerequisite for the academic subject of physics to exist.* The proposal that apparent rationality is illusory, being just the inevitable outcomes of micro-physics, cannot account for the existence of physics as a rational enterprise. But this enterprise does indeed make sense; thus one can provisionally recognise the possibility that free will too is an active causal factor, not directly determined by the underlying physics. Those who claim physics alone underlies consciousness should take cognisance of the true difficulty of the 'hard problem' of consciousness [Chalmers, 1996]; we do not know how to begin to tackle it. However consideration of the causal effect of the human mind is not mandatory in order to argue that higher levels in the hierarchy can be autonomously causally effective; top-down action together with adaptive selection, as discussed above, may well be sufficient.

The key concluding point is that *the emergent higher levels of causation are indeed causally effective and underlie genuinely complex existence and action, even though these are not contained within the physics picture of the world.* The essential proof that this is so is the fact that coherent, experimentally supported scientific theories, such as present-day theoretical physics, exist. They have emerged from a primordial state of the universe characterised by random perturbations that cannot in themselves have embodied such higher-level meanings.

Level 8: Sociology/Economics/Politics
Level 7: Psychology
Level 6: Physiology
Level 5: Cell biology
Level 4: Biochemistry
Level 3: Chemistry
Level 2: Atomic Physics
Level 1: Particle physics

Figure 4.1: **A hierarchy of structure and causation**. A simplified representation of the hierarchy of structure and causation for human beings. Each lower level underlies what happens at each higher level, in terms of physical causation. For a more detailed exploration of this hierarchy, see http://www.mth.uct.ac.za/ ellis/cos0.html.

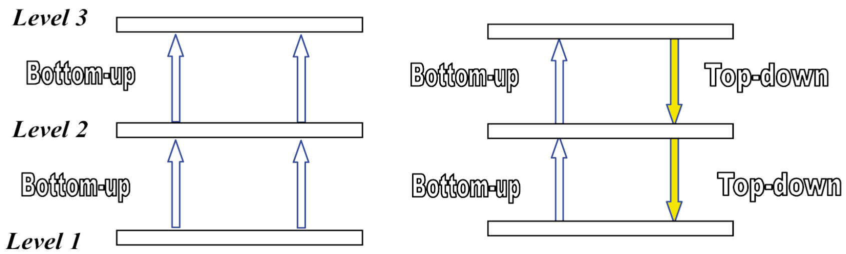

Figure 4.2a: Bottom-up action only. **Figure 4.2b: Bottom-up and Top-down action.**

Figure 4.2: **Bottom-up and Top-down action**. The fundamental importance of top-down action is that it changes the causal relation between upper and lower levels in the hierarchy of structure and organisation, cf. the difference between Fig. 4.2a and Fig. 4.2b.

Cosmology ***Ethics***
Astronomy ***Sociology***
Earth Science ***Psychology***
Geology ***Physiology***
Materials ***Biochemistry***
Chemistry
Atomic Physics
Particle physics

Figure 4.3: **Branching Hierarchy of causal relations**. The hierarchy of physical relations (Figure 4.2) extended to a branching hierarchy of causal relations. The left hand side involves only (unconscious) natural systems; the right hand side involves conscious choices, which are causally effective. In particular, the highest level of intention (ethics) is causally effective.

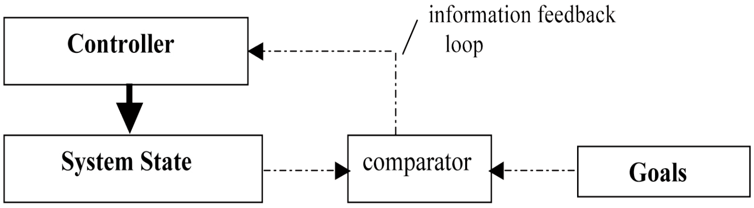

Figure 4.4: **The basic feedback control process**. The comparator determines the difference between the system state and the goal; an error signal from the comparator activates the controller to correct the error [Ashby, 1956], [Beer, 1966]. This is the way that abstract variables such as goals become causally effective in the physical world.

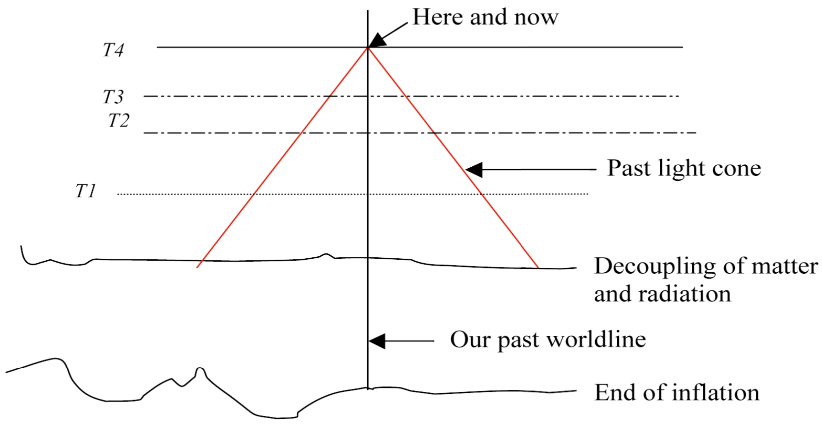

Figure 4.5: **Spacetime diagram of the cosmological context of the development of complexity**. Random fluctuations at the end of inflation generated random fluctuations at the surface of decoupling of matter and radiation. First generation stars (without planets) formed at time T1, second generation stars (with planets) at time T2. First life appeared at T3. The present time is T4. The higher level order and meaning at times T3 and T4 is not explicitly coded into the initial data at the end of inflation or at the surface of last scattering. Thus they come into being during the evolution of complex structures; they are allowed by the initial data but not caused by it.

Possibilities	***Option 1***	***Option 2***	***Option 3***
Order at the LSS	No/Yes	Yes	No
Order today	No	Yes	Yes

Figure 4.6: **Logical Options for the development of complexity in the cosmological context**. One hypothetical possibility is that there is no meaningful order today (Option 1). We reject that possibility as incoherent (you could not discuss it if it were true). Perhaps the order that is present today was present in some coded form at the time of decoupling (Option 2). We reject this too because those perturbations are supposed to have been random (and if higher level order were indeed to have been present then, the major unresolved issue would be how it got there). The true situation is Option 3: random data at the LSS lead to spontaneous processes of structure formation, creating order at later times that was not existent at earlier times in the history of the universe.

5

Scientific Laws and Laws of Nature: Regularities or Necessities?

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For some philosophers, such as Bas van Fraassen and Ronald Giere [van Fraassen, 1989] [Giere, 1988], the notion of scientific law is both problematic and useless. Accordingly, laws should be banned from philosophy of science, and even also from science itself. Yet, the debate on the status of laws continues to loom large in philosophical as well as in scientific circles, with the promise of more to come. In the late sixties and early seventies, with the advent of the so-called semantic approach of theories, philosophers have stressed the importance of models, *i.e.* mathematical structures capable of representing some aspects of real systems. True, this model-theoretic turn has provided a welcome relief from the sterile linguistic sophistry practiced by some heirs of logical positivism. Nevertheless, few would accept that science could work without the propositions that these models, and the systems which they represent, make - at least approximately - true. Among these propositions, some enjoy a privileged status and receive the honorific title of “law”. Ad-

[1]I wish to thank Mario Alai, Mauro Dorato, Brian Ellis, Michael Esfeld, Stathis Psillos and Howard Sankey for their very useful comments on a first draft of this paper.

mittedly, as of today, no consensus on the grounds of this honour seems to be in sight. Although the philosophical literature abounds in numerous incompatible accounts of laws, these can be grouped into two opposite categories, called the "regularity view" and the "necessity view".

In this paper, I propose an overview of what I take to be an attractive philosophical position with respect to scientific and natural laws without entering into too many details. I will first examine the regularity and necessity views and attempt to assess their respective merits and difficulties. I will then defend an account of laws which takes *scientific* laws to be universal statements or propositions[2] made true by empirically successful scientific models, and also made – approximately – true by the real systems represented, *albeit* partially and imperfectly, by these models. I construe a scientific theory as a set of models together with a set of propositions, some of which are laws. Although many authors do not draw the distinction between scientific laws and laws of nature, and concentrate their analysis on the notion of law of nature, I believe that a rough distinction between them at the outset can help to clarify the issues at stake. A scientific law is a universal proposition or statement that belongs to a scientific *theory*. Thus, stock examples such as the (true) statement "All ravens are black" fail to qualify as scientific laws. We may say that a scientific law is also a law of nature if we can provide arguments in favour of real natural dispositions or powers that ground the truth of those laws. In my view, scientific laws are also *laws of nature*. I will argue that the truth of counterfactual conditional statements and the permanence of regularities in nature provide good reasons to believe that real causal powers, potencies or potentialities exist in *nature* and therefore that the (approximate) truth of scientific laws is based on a metaphysics of nature.

[2] I draw the customary distinction between sentences, which are mere linguistic entities containing terms or words, and statements or propositions, which have "truth-makers" such as situations or possible facts. Predicates are terms which refer to properties, natural kinds or universals, according to the terminology used by various authors.

The Regularity View

Unsurprisingly, philosophers with empiricist leanings inspired by David Hume favour the regularity view. It is well-known that, according to Hume, there exists no necessary causal connection between – observable – events, even if those appear to be always conjoined, such as fire and smoke. Sensory experience alone does not permit one to claim that fire will always produce smoke, nor that fire is *necessarily* accompanied with smoke. The necessity that we attribute to a causal connection springs from an unavoidable internal feeling of expectation, an irrepressible subjective tendency to infer the presence of smoke when there is fire[3] (or conversely). Such a necessity however has no objective correlate in the events we observe. The inner feeling of expectation which has its natural source in our observing the constant co-occurrence of some types[4] of events does not by any means warrant the existence of an objective causal connection among them.

Thus, for Humeans, the scientific laws, like Boyle's law, are universal contingent propositions that express mere regularities, *i.e.* observed constant but non-necessary connections among events. It is not impossible that tomorrow we will observe a gas whose pressure would not increase when heated at constant volume. At best, scientific laws are *contingently true universal propositions* whose truth-makers are existing regularities.

Humeans are confronted with a major problem, which van Fraassen calls the "identification problem" : "(...) one must identify the relevant sort of fact about the world that gives law its sense; that is the problem of identification" (van Fraassen 1989, 39). This means, I take it, to identify the feature of the world that makes the statement "It is a law that p" true. For the sake of clarity, we must realize that this question is different from the, perhaps related but distinct, issue of identifying the kind of fact in the world that makes the statement "p" true. We must further be aware that the identification problem has two facets : first, there is the *epistemic* problem of knowing how to distinguish the lawful statements from the non-lawful ones; second, we have the ontological problem of identifying, as van Fraassen says, the kind of "fact about the world" that confers their specific status to lawful statements.

[3] Although the statement "All fires produce smoke" is not a scientific law according to my criteria of nomicity, Hume's analysis can be applied to genuine scientific laws, such as Boyle's law.

[4] The standard distinction between tokens and types is due to Charles Sanders Peirce. For example, there are many coins (tokens) that are worth one euro (type).

Let us look at the *epistemic* problem first: how can we identify the genuinely lawful statements and separate them from merely accidental truths? The contemporary followers of Hume, called neo-Humeans, have struggled with this problem and attempted to devise criteria capable of distinguishing laws such as "All metals expand when heated" from propositions such as "All samples of gold are smaller than 1000 cubic meters". The former is believed to be a genuine law, whereas the latter intuitively seems to only state a fortuitous and accidental characteristic of our universe. In order to single out the nomological from the accidental, John Stuart Mill [Mill, 1846], and Frank Plumpton Ramsey [Ramsey, 1928] pointed out the role played by laws in the context of deductive theoretical systems of statements. By doing so, they paved the way toward an elaborated regularity view which culminated in David Lewis' [Lewis, 1973, Lewis, 1983] sophisticated proposal, called the *Mill-Ramsey-Lewis (MRL)* account of laws.

For Lewis, a law is a proposition that occurs "as a theorem (or axiom) in each of the *true deductive systems that achieve the best combination between simplicity and strength*" [Lewis, 1973, 73; my italics]. Strength is related to the capacity of a theory to account for empirical data. The more empirically successful and informative a theory, the stronger it is. Since we want to avoid theories that are mere compilations or lists of observational reports (such as the "almanacs" mentioned by Lewis) we organize a set of propositions in a hypothetico-deductive theoretical corpus based on postulates or axioms. In this process we gain in simplicity but we may lose in empirical power and no longer be able to predict some observational data. The simplest system is a tautology, which is compatible with all data but whose predictive power is nil. The more balanced axiomatic systems result from a trade-off between these conflicting *desiderata*. Since a given set of propositions can be axiomatized in different ways, which may all equally satisfy the requirement of the best equilibrium between simplicity and informativeness, Lewis defines the laws as the propositions *common to all* these deductive systems. Let me stress that, according to Lewis' criterion, a proposition cannot qualify as a law in isolation, but only when it belongs to an axiomatically formulated theory. In this way, Lewis solves the problem of uninstantiated or vacuous laws, *i.e.* laws which are not in fact satisfied by any real system (such as the Newtonian law of inertia) by pointing out that the adjunction of such laws may contribute to the best balance in simplicity and strength of the whole axiomatic edifice.

Having thus epistemically identified the lawful statements, Lewis can tackle the *ontological* problem of identification. Faithfulness to the core of Humean empiricism according to which laws express only some sort of regularities is a salient feature of his account. The facts about the world that make laws true are the observed regularities. Laws are then considered to be universal *truths* expressing real regularities but no kind of necessity whatsoever. What makes a law "p" true is a real regularity. But what confers to "p" the title of law, *i.e.* what makes the proposition "it is a law that p" true, is not a worldly fact, but the belonging of "p" to a certain type of theoretical systems.

Several well-known difficulties plague the neo-regularist account of laws (see [Armstrong, 1983], [Carroll, 1990], [Dorato, 2005], [Ellis, 2002], [Psillos, 2002], [van Fraassen, 1989]). The application of Lewis' epistemic criterion of nomicity hinges on the availability of axiomatic formulations. Few theories are axiomatized in Lewis' sense[5], even in physics, and some theories may not even be axiomatizable. Moreover, when an axiomatization is available, some alternatives are always possible in principle. It might then be the case that the axiomatizations that exemplify the greatest equilibrium between simplicity and strength are unknown to us. Even if all possible axiomatizations were available, the properties of simplicity, strength and balance between them are not delineated in a sufficiently precise and objective way. These properties may well be just in the "eye of the beholder", without reflecting any objective real feature of the world. Admittedly, the observed regularities are objective; yet, the extra ingredient that Lewis adds to some universal statements in order to raise them to the status of "laws" does not seem to correspond to something observable or real, but appears to be only relative to our human, subjective and practical, interests in organizing knowledge in a deductive handy fashion. Thus Lewis' criterion falls prey to the charge of being epistemic, even "chauvinistic" [Carroll, 1990, 202], *i.e.* relative to our current state of knowledge and our present interests.

In his version of the regularity view, Stathis Psillos [Psillos, 2002] improves on the MRL account in avoiding the defect of subjectivity. Psillos defends a realist position according to which the simplicity of an axiomatic system reflects the objective simplicity of the organization of regularities in the world, which following Mill he calls the "web-of-laws" [Psillos, 2002, 148]. Despite the difficulties we face when we attempt

[5]Lewis adopts Hilbert's sense of axiomatization as a deductive organization of statements, and not Patrick Suppes' for whom to axiomatize a theory is to define a set-theoretical predicate [Suppes, 2002].

to capture the elusive notion of simplicity, such realism seems rather attractive. However, this web-of-laws view does not improve much on Lewis' solution of the *epistemic* problem of identification. It is plausible to contend that the simplicity of a theoretical system has an objective counterpart, but this does not help in practice to decide whether a given statement is lawful or not. On the other hand, there is some progress with respect to the *ontological* problem of identification. Following Ramsey, Psillos posits that "the *world has an objective nomological structure*" [Psillos, 2002, 154]; and this is a fact about the world – as a whole – that grounds the nomicity of lawful statements.

Yet, another serious difficulty looms for the MRL account. The MRL criterion of nomicity fails to comply with the widely accepted requirement that laws imply counterfactual statements, namely "if..., then..." propositions the antecedents of which do not actually obtain. The counterfactual conditional "If I had heated this piece of metal, it would have expanded" is true in virtue of being the consequence of a law. Since, according to Lewis, the law of dilation of metals is a contingent truth, it does not logically imply the truth of the conditional. In another possible world, in which the piece of metal would be actually heated, the metal may not expand [Armstrong, 1993, 69]. Although Lewis struggles to cope with counterfactual conditionals by relying on his view on nomicity, he only manages to do so by means of additional – and controversial – postulates on the similarity among possible worlds (1973). The web-of-laws account also fails to account for the truth of conditionals. If we take Hume's lesson seriously, we have to accept that universal statements about empirical facts cannot logically imply the kind of necessity which is at work in counterfactual conditionals.

Adding to the MRL account's woes, many critics have pointed out that the simplicity of an axiomatic system depends on our choice of the predicates used to formulate the axioms (see for example [Psillos, 2002, 154-155]). To dodge this difficulty, it has been suggested to eschew languages containing "unnatural" disjunctive predicates such as "x is H iff x is F or G" and also Goodmanian predicates such as "grue" ("x is grue if x is green until 1 January 2010 and blue after 1 January 2010"). The universal statements "All emeralds are green" and "All emeralds are grue" are equally well supported by the available empirical evidence on 20 March 2007, but only the first kind of statements may qualify as laws. These predicates intuitively look "artifical" and "unnatural" and, unlike natural predicates, do not seem to refer to real properties that "cut nature at its joints".

The hitch is that it has proved extremely difficult to provide a satisfactory characterization of natural predicates, which refer to natural properties, without appealing to the very notion of nomicity, a move which would plunge us into the whirl of circular reasoning. Of course, Lewis is well aware of this *aporia* and has attempted to characterize natural properties in various ways [Lewis, 1983, 347-8]. One of his attempts, which is more in line with empiricist orthodoxy, capitalizes on observed similarities among individual objects, called "particulars". "To be red" or "to be a raven", for example, would, according to Lewis, refer to natural properties because these properties are shared by a variety of particulars. The trouble with this move is that no immediate correlate in observation corresponds to most scientific terms such as "temperature", "heat", "charge" and even "to be metallic". It thus seems problematic to rely on observed similarities and dissimilarities in order to detect which of the scientific properties are also natural properties[6].

The Necessity View

The opponents of the neo-regularists object that they are unable to solve the *epistemological* problem of identification since there is no objective feature of our theoretical systems that permits to recognize nomological statements. They also object that the *ontological* problem of identification cannot possibly be resolved on the basis of any observable characteristic of the world. For the assertion "It is a law that p" to be true, it is not enough that p describes some regularity. The assertion "It is a law that p" must have something real and objective that *makes* it true. All propositions must have a *truth maker*. This "truth-making principle" is a consequence of a correspondence view of truth according to which the truth is some sort of relation between the proposition and a fact or situation.

The necessitarians have attempted to solve the ontological *problem of identification* by contending that genuine laws, unlike accidentally true universal propositions, state some kind of *necessity between properties*. Fred Dretske [Dretske, 1977], David Armstrong [Armstrong, 1983] and Michael Tooley [Tooley, 1977] claim, with some variations, that a scientific law is a *singular* statement that expresses a non-empirical fact, namely a *relation of necessity among universal properties*. What *makes* a

[6]For the discussion of other difficulties encountered by Lewis' philosophical view on natural properties, see Carroll [Carroll, 1990, 199-202].

lawlike universal statement, such as "All metals expand when heated"[7], *true* is the existence of a relation of necessitation, written "N", between the universals referred to by "heated metal" and "dilation". For two universals denoted by "F" and "G", the law is the statement "N(F,G)". This account of lawhood is called the "ADT view" and offers a plausible solution to the ontological problem of identification. Following Stathis Psillos [Psillos, 2002, 167-169], let us have a closer look at Armstrong's later elaborated version [Armstrong, 1993] of the necessity view.

For Armstrong, a *universal* is a general and repeatable feature of nature, such as being green, heavy, smooth etc. Only universals that have instances or are exemplified in the world can exist. On this issue at least, Armstrong sides with Aristotle against Plato. The necessitation relation N between universals F and G is a *contingent* relation that obtains in our world, and not necessarily in all possible worlds. In some other world some tokens of F could fail to be also tokens of G. This allows Armstrong to avoid putting *scientific* laws on the same footing as logical laws or tautologies, which are true in all possible worlds. Nomic necessity is weaker than logical necessity. For Armstrong, a law is a law in our world only and may not be a law, nor even be accidentally true, in another possible world. For example, in another possible world, the universals denoted by the predicates "to be a fire" and "to produce smoke" may not be necessarily related. In such a world there could be instances of fire not followed by instances of smoke, unlike what happens in our actual world.

According to the ADT view, the necessity relation holding at the level of universals also *implies* a necessity relation at the level of the particulars that instantiate them. At this point the proponent of the necessity view is confronted with a logical problem, namely the *inference problem* [van Fraassen, 1989, 39]. It is far from obvious that a proposition expressing a second-order relation N at the level of universals (properties, relations etc.) logically entails a statement expressing a relation of necessitation between the instances of these universals, *i.e.* the particular things that exhibit these properties. Does a necessity relation between the properties denoted by "heated metal" and "dilated" warrant the truth of the statement "All heated metals expand"? To put it formally, one may question the truth of the implication:

$$\mathrm{N(F,G)} \longrightarrow \mathrm{(x)\ N(Fx} \longrightarrow \mathrm{Gx)}$$

[7] To be complete, one should add the mathematical law of dilation of metals (see below).

Armstrong is confronted with the challenge of articulating an *explication*[8] of the second-order relation N(F,G) such that it is weaker than logical necessitation but sufficiently strong to support a necessary connection at the level of the individuals which instantiate the properties F and G.

Firstly, Armstrong postulates the existence of universals in order to *explain* the *similarities* between some particulars. Red things are red because they are instantiations (or tokens) of the same universal or (type) "red". Let us denote by ϕ and ψ second-order variables that range over properties (first-order variables range over individuals). Since experience shows us the constant conjunction or co-instantiation of some universals, such as the ones denoted by "heated metal" and "dilation", "fire" and "smoke" etc. Armstrong postulates the existence of a universal N(ϕ, ψ) which accounts for the similarity of these various repeatable conjunctions. Given that the variables ϕ and ψ range over properties, N (ϕ, ψ) is a second-order relation exemplified by N(F,G), N(G,H) etc.

Now, and this is a major move, Armstrong claims that the relation N and the *causal* relation are one and the same. The necessitation relation N between universals (types) F,G is the very same relation that holds among instantiations (tokens) of these universals. Moreover, this causal relationship is *directly observable* in singular examples, like feeling the weight of my own body. This claim is resolutely non-Humean. Empiricists emphatically deny that the causal relation is directly observable.

Equipped with all this machinery, Armstrong feels that he is in a position to claim that he has supplied the *explication* of the relation N and that he has solved the inference problem. The implication "N(F,G) $\longrightarrow$ (x) N(Fx, Gx)" simply becomes "analytic or conceptual" [Armstrong, 1993, 421-422].

Even if we accepted Armstrong's solution to the inference problem, several difficulties remain unresolved for the ADT view. First of all, as with the RML account, the criterion of nomicity rests on the possibility of sifting out the right predicates, referring to correct universals – namely, the *natural properties* – from artificial predicates. Since the epistemic identification of natural properties is achieved by rely-

[8]There is a difference between an "explication" and an "explanation". An explication makes explicit a concept or a notion such as lawhood, whereas laws may play a role in the explanation of some phenomena.

ing on sensory experience, failing to pick out the right properties could result in mistakenly taking accidental coincidences for *bona fide* instantiations of the necessitation relation. Therefore, the proponents of the ADT account do not seem to be in a position to overcome a major objection addressed to the regularity view, namely that it offers no satisfactory solution to the epistemological problem of identification. A second difficulty is raised by the existence of probabilistic laws such as the laws of radioactive decay. Armstrong does deal in great detail with this problem, but his solution has been shown to be inadequate by van Fraassen [van Fraassen, 1989, 109-116]. Thirdly, even if we concede that the causal relationship among particular tokens is observable, how can we justify the claim that the *same* causal relationship holds at the level of universals or types? [van Fraassen, 1993, 436]. Fourthly, most of Armstrong's examples are drawn from ordinary language and commonly observed facts. We can then raise against Armstrong the same objection that was levelled against Lewis. How can we make a case in favour of the naturalness of a scientific property since, more often than not, scientific properties are quite remote from direct experience?

Last but not least, it seems problematic to identify a law with a relation of necessitation between properties. Lawful statements do not literally refer to such a relation but to some regularities. This is the origin of the inference problem encountered by the ADT view. As said above, I prefer to call "laws" a specific class of statements. It is then plausible to claim that what grounds the truth of "it is a law that p" is the existence of a relation of necessitation between natural properties, but what makes p true is the existence of regularities. Even if it can be shown, as Armstrong argues, that the relation of necessitation is causal and warrants the regular co-instantiation of natural properties, the truth-maker of "p" is a regularity if "p", as I recommend, is to be literally interpreted.

Scientific Realism

Confronted with the difficulties which beset both the regularity and the necessity views of laws, Cartwright [Cartwright, 1983], van Fraassen [van Fraassen, 1989] and Giere [Giere, 1999], among others, have urged to abandon all attempts to articulate a philosophical account of lawhood and to concentrate instead on the structure of scientific models. Typically, this attitude has been favoured by philosophers who advocate a *semantic* or *model-theoretic* approach of theories according to which theories are first of all models, i.e. mathematical structures susceptible of approximately representing some aspects of actual systems. In the opposite camp, we find those who mainly defend a syntactic view of theories, according to which theories are sets of propositions – preferably, but not necessarily – organized in axiomatic systems. The philosophers who prefer the *syntactic* approach are inclined to give a prominent role to scientific laws and have struggled, as we saw, to devise precise criteria of nomicity.

The appeal to scientific practice, which remains a recurring incantation in some circles nowadays, does not help to resolve the dispute. It certainly is correct to point out that scientists do construct models, but it is obvious that they also resort to what they call "laws" to construct them and that many scientists, especially in physics, but also in other disciplines such as biology and psychology, still strive to discover true general statements about real systems in the world. Even the staunchest partisans of the semantic approach stress that models not only function as possible representations of real systems, but that they also make true or satisfy some sets of propositions [Giere, 1988]. I am quite sympathetic to the model-theoretic approach whose main - though not sole – merit is to draw our attention to the non-linguistic ingredients of our scientific constructions and the ways in which these constructions succeed in representing. Nevertheless, it would be an error to neglect the importance of universal propositions and the information they convey about real systems. Fidelity to scientific practice – if I may resort to this argument too - forces us to recognize the prominent role that laws continue to play in science. Failing to do so would lead to a considerable impoverishment of our understanding of both scientific practice and scientific theories. Hereafter, I will take a *theory* to be made of a set of statements, which may be called a "theoretical *corpus*", supplemented with a class of models or representations of real systems. Roughly, the *models* make the propositions of the theoretical *corpus* true, whereas these propositions, when applied to real systems, are approximately true if the theory is empirically adequate[9].

I propose to *epistemologically* identify scientific laws as the *(approximately) true universal propositions used to construct empirically successful theories in science*, without at this point entering the debate about the grounds for their truth (such as regularities in the world, relations between natural properties, causal powers etc.). As in the MRL approach, universal statements can be called "laws" within theories only. This

[9]Boyle's law for example, is exactly true for an ideal "perfect" gas; when applied to a real gas, it can only be approximately true.

criterion is rather liberal since it allows theorems to be laws. But it suffices to expel from the paradise of lawfulness not only isolated statements such as the worn-out example "All ravens are black"[10] but also accidental generalizations like "All coins in my pocket are euros". Granted, this criterion for identifying laws is parasitic on the previous acceptance of the distinction between scientific and non-scientific theories. Since I am unable to enter into a full discussion of this issue here, I will simply assume that a theory is scientific if it can be empirically tested by means of rigorous and reliable methods. In the – rare – cases of the availability of "strongly empirically equivalent theories" (Reichenbach), that is theories that are confirmed or falsified by the same empirical data, the laws are the well-confirmed and true universal propositions common to them.

Within this perspective, the *epistemological* identification problem is solved by assessing the truth of laws in the context of scientific theories, leaving aside for the moment what their truth-maker is. This is a notoriously thorny issue. *Antirealists* at most believe in the truth of statements which describe the observable aspects of things. Accordingly, only generalizations about phenomena could qualify as scientific laws. *Realists* on the contrary insist that some, but not all, of the universal statements employed in the construction of successful theories hit on unobservable features of real systems. A satisfactory account of laws must rely on arguments in favour of the – at least approximate – truth of some of the universal statements which are parts of well-established theories. I have defended a *moderate* (*fallibilist* and *selective*) version of scientific realism on various occasions (see [Ghins, 1992, Ghins, 1998, Ghins, 2000, Ghins, 2005]). Recent arguments for scientific realism can also be found in the writings of Lawrence Sklar [Sklar, 2000], Howard Sankey [Sankey, 2001] and Stathis Psillos [Psillos, 2002], to only name a few.

Moderation stems from the fact that our theories, to the extent that they can only be confirmed by observations and measurements, are falsifiable and may contain ingredients that have no correlate in reality. We did not have to wait for Hume to realize that mere observations, no matter how numerous, are incapable of establishing final and definitive truths. Many philosophers of ancient Greece – and Aristotle was among them – were well aware of that! For the better or the worse, the future

[10] I accept of course the truth of "All ravens are black" and other well-established empirical generalizations. I simply deny them the title of "scientific law", in line with the MRL account. Such generalizations may be useful for the progress of science and lead to the construction of (successful) theories.

may be full of surprises. *Selectivity* is also crucial since we all know that our theories-models are constructed in such a way that, whereas some of their assertions may be true, some of them cannot possibly be so.

Some real systems approximately behave in accordance with scientific laws in the sense that the models which partially and approximately represent them are not only empirically successful but also represent some of their unobservable characteristics. Some laws are therefore approximately true for some systems and do not apply to others. The laws of the pendulum are true for oscillating systems satisfying certain conditions and inapplicable for other systems. If a system is not a pendulum which satisfies certain *ceteris paribus* conditions, also called *provisos*, then Galileo's "law" of isochronisms of oscillations of small amplitude cannot be successfully applied to this system.

Now, some laws are more general than others. Kepler's laws only hold for two masses which solely interact by means of a gravitational force. On top of that, external perturbations due to other masses must be weak and some initial conditions have to be satisfied. However, we have strong reasons to believe that all physical entities, fields and particles are affected by gravitation. Simply because when we are interested in the motion of a particle or the variation of a field and we want to construct a model that makes correct empirical predictions, we must take gravitation into account, or we have to make sure that its influence can be neglected.

The realist view (RV) of scientific laws that I briefly presented succeeds in solving the inference problem. If it is a law that p, then p. If a universal scientific proposition p is true, then the situations or processes it describes do occur in the world. However, on this account, there is no reason to maintain that laws are in any sense necessary. If laws are epistemologically identified as true universal propositions belonging to scientific theories, they are only descriptive and carry no modal force. They may just be accidentally true.

A Philosophy of Nature with Causal Powers

It should be clear at this point that the *logical* problem of inference and the *epistemological* problem of identification of scientific laws, construed as statements, can both be solved by the realist view. Yet, the RV leaves open two questions, which can only be addressed by entering the territory of philosophy of nature.

First, the RV does not explain why laws entail *counterfactual conditionals*. We feel that we are in a position to claim that “If I heated this piece of metal, then it would expand”, *i.e.* that its length would increase according to the equation:Δ l = kΔT. We believe in the truth of this counterfactual because it seems to be a consequence of a well-established law. But since according to RV laws are merely descriptive statements they cannot logically imply propositions which involve modalities, namely possibility or necessity. Thus, if the inference from laws to counterfactuals is legitimate – and our intuition supports that claim – laws must have some “modal force”. What are the grounds of such a modal force?

Second, the RV does not account for the existence of *regularities in nature*. This is an old problem, nearly as ancient as philosophy itself, and connected with the problem of the justification of inductive reasoning. It is a fact that many of our scientific theories are remarkably accurate and reliable. Numerous real systems in nature can be successfully modelled and their behaviour precisely predicted. They exhibit a regular and uniform pattern of behaviour in time. We may take this as a brute fact – as empiricist philosophers do – or attempt to explain it[11].

A possible explanation of regularities in nature is that laws impose a regular pattern of behaviour on entities and systems which by themselves are passive and inert. This is the view inherited from the thinkers associated with the scientific revolution (Descartes, Kant), who were very reluctant to accept the existence of Aristotelian internal powers or potentialities rooted in the essences of things and believed that laws somehow govern[12] or rule a passive inert matter. However, laws construed as *statements* do not impose anything to reality. Statements are powerless in this respect. If what makes laws true are mere regularities, as the defenders the regularity view claim, laws only express regularities and do not explain why these occur with some necessity. As David Hume emphasized, the fact that something is so does not imply that it *ought* to be. I surely want here to avoid falling into the trap of the “naturalistic fallacy”.

[11]Many realists believe that the so-called “no-miracles argument” (Putnam) suffices to vindicate scientific realism as an explanation of the truth of empirically successful theories. This argument, however, is flawed (see [Ghins, 2002]).

[12]On the conception of laws as governors or rulers of nature see [Mumford, 2004], [Ellis, 2006a] and [Psillos, 2006a]. I here agree with Psillos that the governing of laws is – at best – a metaphor.

On the other hand, if the truth-maker of "It is a law that p" is a relation of necessitation between natural properties, as the proponents of the ADT view contend, and if the inference problem could be solved, we would have an explanation of the existence of regularities. However, the above mentioned difficulties which undermine that account prevent us from adopting it.

In line with the Aristotelian tradition, according to which the observed regularities are grounded in forms or essences, *i.e.* internal principles of action possessed by substances or entities, Rom Harr and Edwin Madden [Harré and Madden, 1975] have suggested to endow real entities and systems with *intrinsic causal powers*. This position has been taken over and fleshed out, *albeit* with some variants, by Nancy Cartwright [Cartwright, 1989], Brian D. Ellis [Bigelow, 1992, Ellis and Lierse, 1994, Ellis, 2002], Caroline Lierse [Bigelow, 1992, Ellis and Lierse, 1994], John Bigelow [Bigelow, 1992], Stephen Mumford [Mumford, 2004], Mauro Dorato [Dorato, 2005], among others. These causal powers are modalities or dispositions which manifest themselves in some favourable circumstances. For example, a body has the capacity to fall. This means that, if the appropriate circumstances are actualized, it would indeed fall. If these conditions obtain, the body cannot fail to fall. In other words, bodies do fall in virtue of some internal necessity rooted in them. All material bodies are endowed with a causal gravitational power which necessitates the occurrence of a specific causal process – namely, fall – in an appropriate environment.

According to Brian Ellis' "new essentialism", some properties are *natural kinds* in the sense that the entities (bodies, systems, fields etc.) that exemplify them will, as a matter of *necessity*, always engage in a certain kind of causal process, provided the adequate "triggering" circumstances are realized. These circumstances are expressed by propositions referred to in the philosophical literature as *ceteris paribus* conditions or *provisos*. Falling bodies are observed as a matter of course. All things being equal, *i.e.* in the same conditions, all newly observed bodies will also fall. This is because, material bodies possess an internal tendency, a causal natural power or disposition[13] to fall which cannot be withdrawn without the body ceasing to be what it is.

Many a contemporary reader will perhaps scoff at this neo-Aristotelian conception, which is believed to have been definitely refuted, at least in

[13]In what follows, the terms "disposition", "potentiality", "potency", "tendency", "capacity", "causal power" etc... will be regarded as synonyms.

the context of current mainstream philosophy of science. Of course, the explanation of opium's capacity to induce sleep on the basis of the putative existence of an inner *virtus dormitiva* has been ridiculed long ago by Molière. However, if we are presented with a sample of opium, or another kind of substance, and if we are told that it is soporific, this gives us some precious information about what can be expected to happen when ingested by a human. To be soporific is a disposition or modal property, a power to induce sleep in appropriate circumstances. I concede that calling this power "*virtus dormitiva*" does not cut much explanatory ice. Such a gloss would simply reveal, if anything, one's pedantry and desire to impress the audience with one's (limited) knowledge of Latin, rather than a dedicated search for a light-bringing explanation. It was such an attitude and empty use of words, rather than Aristotelian physics, which was the real target of Molière's irony.

Positing the existence of a capacity or power or potency, whatever one may choose to call it, does provide an explanation of the regular behaviour of the entity in which this power is present. By positing a causal power, we do not merely re-describe a regular pattern in new words, but we add the extra claim that this regular pattern is grounded on a dispositional property rooted in an entity. This move effects a transition from the purely descriptive level to the normative level. Internal powers impose, necessarily, a pattern of behaviour to the entities that possess them[14].

Such an explanation of a regularity is not scientific, but metaphysical. A scientific explanation of opium's soporific capacity would rely on the presence of chemical components which react with human organisms in ways that should be accurately described. But the challenge of providing an explanation of regularities will re-emerge at the microscopic level.

In science, as we saw, the laws are used in the context of theories-models and are more often than not formulated in mathematical language. Moreover, scientific laws mostly express relations rather than attributing monadic properties to some entities. Newton's law of gravitation states a mathematical relation between a distance, a force and two masses. The pre-eminence of relations has frequently been heralded as a revolutionary change with respect to Aristotelian natural philosophy, which lays emphasis on the individual properties of substances.

[14]Granted, if the appropriate triggering circumstances are never realized, an entity may never engage in some kind of behaviour. A scientific theory may imply statements about the possible occurrence of regularities that never obtain.

But Aristotle's insight on potentialities can be transferred to a philosophy of nature which gives relations its due. For an entity, like a body or a particle, to have a mass – and the property of having a mass can be considered to be a natural property – implies that the entity has the disposition or power to *interact* with other massive entities in obedience to Newton's mathematical law. Similarly, for a particle to be an electron implies that it has the capacity of interacting with other charged particles in conformity with mathematical laws. Thus, causal powers can be conceived as relational capacities, and yet be inherent to the entities themselves.

Unlike Aristotle for whom potentialities are inherent to substances, new essentialists take dispositions, capacities or propensions to be *properties of properties.*

> "We claim that among the essential properties of a property there is the propension or disposition of anything having it to show a certain kind of behaviour in a particular context. What science studies and codifies are the manifestations of these dispositions" [Bigelow, 1992].

For my part, I rather favour an ontology of entities or substances (conceived in a sufficiently broad sense; for example, a field is a substance) endowed with modal relational properties, rather than an ontology of monadic or relational properties only. Yet, I agree with the new essentialists that the recourse to dispositions or powers provides an explanation of the regularities expressed by the scientific laws. In fact, scientific laws may inform us about the inner natures of things in a precise way, whereas common dispositions such as "soporific", "fragile" etc. usually refer to complex sets of dispositions of the individual components of everyday objects. I said "may inform us" because we are never absolutely certain that a basic scientific law hits on real natural powers; after all, we may err. Nevertheless, the well-established fundamental scientific laws are our best bet about what natural properties and relations exist in the world. Such scientific laws very likely also are laws of nature.

Instead of construing laws as truth-makers, I take laws to be *statements* or *propositions* expressing relations between (universal) properties possessed by some entities. For instance, the laws of the electromagnetic field – Maxwell's laws – express relations between natural properties such as "having a charge", "having a field intensity" etc. These natural properties and the way they are related capture the essence of the electromagnetic field, namely the causal power or disposition that such a field possesses in order to interact, typically with electric charges or magnets, as stipulated by the mathematical laws. In the same way, an electron, designated by a state function ψ in quantum mechanics, has the power to behave in a certain manner described by Schrödinger's equation. Of course, laws have their domain of application; in some cases Maxwell's equations can be used, and in other situations, we have to mobilize the resources of quantum mechanics. This poses a problem for the new essentialists, which does not seem to be sufficiently addressed by them. Nevertheless, I believe that it can be argued (it is impossible to get into more technical issues here) that Maxwell's laws, for example, convey an approximate knowledge of the real causal powers of fields and charges.

It must also be mentioned here that probabilistic laws raise another sort of worry. Dispositions can be extended to propensities or tendencies to engage in a kind of process with some degree of probability, and are not restricted to deterministic processes only (see [Ellis, 2002, 78] and also [Tanzella-Nitti, 1997]).

According to the view presented above, scientific laws are universally true propositions belonging to well-established scientific theories describing actual regularities in nature. Literally, laws do not assert that some entities possess causal powers grounded in their essential properties. But "it is a law that p" asserts that the truth of p is grounded on the real, relational natures of entities and their dispositions to engage into specific processes. In other words, the truth-maker of "it is a law that p" is the existence of causal powers or dispositions in substances.

Under this metaphysical view, the *ontological* problem of identification is solved and scientific laws acquire the status of necessary laws of *nature*. An electromagnetic field or an electron could not continue to be the same sort of entity should the laws be different. Simply, because changing the laws would also modify the essences of things. Ellis rightly stresses that electrons are the same in all possible worlds. There could perhaps exist worlds without electrons, but if electrons exist, they must interact according to Maxwell's laws, otherwise they would cease to be electrons and be another type of particle. The necessity of a law is therefore rooted in the essence of some entities. Laws are, as Ellis maintains, *necessary a posteriori* because the causal powers of entities cannot be known *a priori*, by simple analysis of the meanings of the terms involved. They must be discovered, through (often painful) scientific investigation.

According to the account I defend, there is no inference problem. Laws, as I repeatedly said, state regularities. If "it is a law that p" is true, then some entities possess some specific real dispositions to behave in certain ways in given circumstances. It follows that, if these circumstances obtain, some regularities will occur in the world.

Although I find myself unable to subscribe to Ellis' physicalist pronouncements [Ellis, 2002, 86], I cannot help to find his grand view of nature and its laws particularly attractive, provided it is supplemented with the insights of the model-theoretic approach. Even if laws are metaphysically grounded on universal modal properties or powers, the only epistemic access we have to laws and natural properties is through the success of scientific models and the observation of recurrent regularities. The regularists surely are right on this count. But, in order to ground counterfactual conditionals and to account for the wide-ranging occurrence of impressive regularities, the appeal to intrinsic dispositions or causal powers of substances[15],*albeit* unashamedly metaphysical, appears to be the most promising option.

Conclusion: Good or Bad Metaphysics?

An empiricist such as Bas van Fraassen will be quick to raise powerful objections against such a metaphysics of natural powers. For him, the absence of direct empirical access to modalities in general, and *a fortiori* to internal causal powers, pulls the carpet under the feet of the metaphysician and makes his ontology crumble. Moreover, it is illegitimate to work out philosophical problems by merely postulating the existence of entities for which no independent evidence is available [van Fraassen, 2002, 10].

It is correct to claim that the sole ability to solve the ontological problem of identification cannot be considered a sufficient reason in favour of

[15]In a recent paper, Psillos [Psillos, 2006b] develops a strong conceptual argument against the thesis that all properties are pure powers (not grounded on non-power or categorical properties) and that current physics supports this thesis. Since I believe that no physics (whether past, current or future) can provide arguments for or against any metaphysical view on properties, I agree with Psillos that current physics does not favour a metaphysics of powers: we need genuine philosophical arguments. My position is that *some* (not all) properties are powers. These powers are grounded in the – categorical - properties of substances, which, in virtue of these categorical properties, have causal powers. Unlike Ellis and Mumford, I do not believe in the existence of pure, irreducible, powers. This Aristotelian (and Leibnizian) position avoids the regress that invalidates a metaphysics grounded on pure powers.

the existence of causal powers. Even if it could be shown that the solution offered is the best that could possibly be envisaged – which in most cases is an unreachable goal – we have no guarantee that the proposed solution allows us to reach out to external real modal properties. Thus, even if it could be shown that the existence of causal powers in nature delivers the best possible explanation for the occurrence of observed regularities and the truth of counterfactuals, these results alone would be insufficient to justify our belief in the existence of causal powers, simply because there is no *a priori* warrant that reality matches our human requirements (or desires) for understanding and intelligibility. This is why empirical evidence is indispensable to support any existence claim. The question we have to face is then: what empirical grounds can we muster in favour of the existence of causal powers and dispositions?

First of all, we have a personal inner experience of powers. While I am sitting, I know very well that I can get up and walk. And I also know that other people have all sorts of capacities and dispositions, on the basis of my own experience and of what I can observe in the actual behaviour of others. This – admittedly trivial – remark is all we need to make the point that modalities cannot be easily dismissed, even by an empiricist[16]. I readily acknowledge that these observations are not sufficient to support the universal claim that *all* existing entities have intrinsic powers or dispositions. Internal capacities may perhaps be confidently extended to animals, plants and even all living beings. But to further extend dispositions to rocks, electrons and galaxies may seem far too bold a claim, suspiciously tainted with anthropomorphic overtones. Yet, if one embraces a physicalist reductionist *credo*, which consists in the belief that all existing entities are made of fields and elementary particles (electrons, photons, quarks etc.) and that all properties supervene on the properties of these elementary entities, there is no reason to exclude the possibility that these entities also have causal powers. Surely, I do not wish to plead for physicalism and reductionism, but I think it is important to realize that if one wishes to maintain that human beings are, at the end of the day, reducible to elementary physical constituents then it is only a matter of coherence to grant that all existing entities are endowed with causal powers. Within a physicalist reductionist per-

[16]Stathis Psillos pointed out to me that we have the personal outer experience of the sun rising every morning. Yet, we know now that the earth rotates. Thus, our personal experience may be misleading. I quickly reply to his objection. First, the contradictor must put forward an argument against the reliability of a particular experience, and not simply remark that we may err. Second, the experience of our power to do things is different in several respects. For example, we experience the repetitive feeling of this power with respect to a large variety of possible behaviours.

spective, the dispositions inherent to human beings cannot spring from without and must eventually be based on the existence of causal powers at the level of the elementary physical components of matter.

The positive argument I would like to offer in favour of the existence of dispositions for all existing entities is the following. If we accept that we are endowed with causal powers, then we have the capacity to act on external *prima facie* "inanimate" or "inert" systems, *i.e.* systems which at first sight are passive and deprived of inner powers. Few would dispute that such a capacity of action has been enormously enhanced by science. In appropriate conditions, each time we decide to drop a stone, it falls according to a quantitative law which is verifiable at any time anywhere on the surface of the earth. Since external systems react in various and predictable ways to our actions, it does not seem unreasonable to suppose that external systems have the inner capacity to react to our actions and operations in specific, quantitative ways and that, when the appropriate circumstances hold, they will necessarily react in those ways. This contention is further buttressed if we accept the truth of counterfactual conditionals. Few doubt that an electron under the sway of an electromagnetic field would behave in accordance with Maxwell's laws. If we admit that counterfactuals such as these are true, one is led to posit the existence of internal dispositions, powers or potencies in virtue of which the systems endowed with them are constrained to behave in a certain way.

Positing the existence of causal powers manifested by the processes described by scientific laws conveys a global coherent picture of nature as a totality organized by these laws. The global coherence of this picture provides a further argument in favour of the view presented above (Ellis). Again, such an argument might lack the appropriate force to convince a Humean empiricist. But in the absence of any plausible alternative explanation of the truth of laws, such a philosophy of nature appears quite attractive.

Bas van Fraassen, who is a leading self-proclaimed "immoderate empiricist" [van Fraassen, 2000, 1660], promotes a tolerant conception of rationality, which he compares to the English law. Whereas in the Prussian legal system what is not explicitly allowed is prohibited, English law is based on the principle that what is not explicitly prohibited is allowed. Similarly, if there are no reasons against believing in something, then this belief attitude is rational.

> "(...) what is rational to believe includes anything that one is not rationally compelled to disbelieve (...) *Rationality is only bridled irrationality*" [van Fraassen, 1989, 171-2].

I will here abstain to engage in a discussion on the merits of such a conception of rationality. My only hope is that I managed to convince the reader that the belief that the approximate truth of scientific laws is grounded on essential dispositions of natural entities is not irrational and, furthermore, is an eminently rational belief. There exist positive reasons it its favour and no knock-down arguments against it.

6

Consumption and Happiness: Christian Values and Sustainability

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In this essay[1] we argue that sustainable consumption and production practices are fundamental to the future success and planetary survival of humankind and that these practices have been informed by Christian teaching about stewardship and responsibility. The core idea is that there are problems with unsustainable patterns of consumption and production, not least in their low impact on individuals' well-being and happiness, and that we should see what a blueprint based on the Christian value system might look like for the continuous repair and maintenance of the created order, and what contribution would be expected of us as "reasoned agents" of change rather than "needy patients". The complexity of a strategy directed towards sustainable consumption and production becomes evident if we consider science, technology and engineering, consumption behaviour and lifestyle,

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industrial and business practices, fiscal measures and socio-political initiatives. We have chosen to focus on life in more developed countries because this is where the greatest challenges of overconsumption and profligacy exist, topics we too often prefer to sideline. We examine how Christian values provide powerful and timely insights into stewardship responsibility, the integrity of the created order, and care for the needs of future generations. This is not to relegate the importance of the challenges in less developed countries, nor to ignore the significance of a comprehensive global ethic, but these are topics that will be explored further on a future occasion.

Introduction

Consumption has increased immensely over the second half of the last century. Overall economic activity has quintupled and energy use has more than quadrupled as world population has more than doubled. Food production has tripled in the same period. Business-as-usual scenarios suggest a slowing of these trends rates over the next 50 years though consumption rates are predicted to increase at well beyond the rate of population increase and energy is anticipated to show a five-fold increase over the next 100 years [Heap and Kent, 2000]; [Heap, 2003, Heap, 2004]. One of the negative consequences of these trends is industrial toxic waste; much of the waste-sink capacity in rich industrialized nations has been used up so that it is distanced from end consumers by making its way around the globe to less developed countries where it contributes to the local economy but at serious environmental cost [Princen, 2002].

Among the positive features of the consumer culture is the ability of more people to meet their basic needs. Nowadays, more than 25% of individuals worldwide live a lifestyle once limited to rich nations. This laudable improvement which is associated with sustainable development means that while the average Chinese and Indian still consumes much less than the average North American or European, their combined consumer class is larger than that in all of Western Europe. In China 240m people are classified as “new consumers” and this figure will soon surpass the total number of consumers in the USA. At least one-fifth of global car ownership is attributable to the “new consumers” and by 2010 this figure could have risen to one-third [Myers and Kent, 2004]. The astonishing change of living standards in China over the past 20 years has resulted in people reporting a value 2.5 times greater than that reported by respondents in 1994 reflected in the ownership of colour televisions (82% now owned in households), landline phones (63%), video players (50%) and mobile phones (at least one phone in 400m households). However, the ratio of Chinese expressing satisfaction with the way things are in their lives to those who are dissatisfied has actually eroded over time mostly because of the ills associated with the urban environment compared with the lifestyle of their rural counterparts [Gallup, 2005].

Consumption's headlines reflect prosperity. Last year energy giant Royal Dutch/Shell posted a record net profit of £9,300m, not far behind Exxon Mobil at £13,270m. The retailers, Tesco plc, announced a UK turnover of £24,000m, up 47% on 2000 and amounting to about 1 in every £8 spent by the country's shoppers. With such reminders of rampant consumption it is not surprising that watching consumers' behaviour has become an industry in itself so far as advertisers and marketing executives are concerned. They spend $117 bn a year on commercial advertising to maintain and enhance the momentum of rising consumption, and they know that factors which generate personal choice and preference and a feeling of prosperity through happiness and satisfaction are important for brand loyalty. What goes on inside the shopper's head, however, is another matter and leads to scientific questions about which specific regions of the brain are involved, how they operate, how they are linked to memory, decision-making, fulfillment and self-image, and whether they can be influenced by externalities. The popular idea that there may be a "buy button" in the brain has attracted the attention not only of neuroscientists but of marketing executives whose interest is to exploit further the processes that govern consumer-critical decisions.

And yet, there is mounting evidence, as discussed below, that consumption and economic prosperity have not delivered the "promised land" and it is important therefore to delve into the reasons behind the sustainability paradigm and to relate them to the foundations of cherished values that are foundational to certain religious principles and attitudes as illustrated in Table 6.1.

If we are to formulate a Christian framework directed towards sustainability it calls to mind an important medieval distinction used by the economist and Nobel Laureate Amartya Sen who argued that the focus in the debate should be placed not only on people as human beings whose needs deserve attention as "needy patients", but on their role as "reasoned agents" whose freedom to determine what we should safeguard and sustain can extend far beyond our living standards and our own needs [Sen, 2003]. The sustainability approach should celebrate and try to safeguard human freedoms, says Sen, much as Paul insists in his letter to the Galatians, "it is for freedom that Christ has set us free" (Gal 5:1). Those who first encounter the idea of sustainable consumption and production are often worried that it will require the introduction of draconian rules and regulations, but "sacrifices in living standards may not actually be substantial – in fact, quite possibly, just the contrary" [Sen, 2003, 14].

In this essay we will argue that sustainable consumption and production practices are fundamental to the future success and planetary survival of humankind and that these practices derive their substance from Christian messages and values about stewardship and responsibility. We concentrate on life in more developed countries because they face the formidable challenges of unsustainable consumption and production, whereas in many less developed nations the challenge is one of underconsumption and low levels of production, though the two problems may not be independent as we shall see later. This is not to relegate the importance of the problem in less developed countries but to promote the awareness of our own dilemma which we too often prefer to sideline. Neither is it our intention to deny the wholesome significance of a global ethic such as that developed by the Parliament of the World's Religions in 1993 which encompasses parallel contributions of other world faiths [Küng, 1996]. It is our intention to focus on the Christian message because it has not always received the attention it deserves in this area. Advocating a conscious move towards sustainable consumption and production is a topic of such complexity that it demands a multidimensional and multidisciplinary analysis if a strategy that speaks to the wider community including policy makers is to become evidential.

What Drives Consumption?

Population growth is frequently perceived as a macro-driver of consumption and unsustainability, but the picture is not always as straightforward as is sometimes suggested. Britain has a population growth of 0.1% producing an extra 59,000 people per year to go with today's 60 million population. Bangladesh has a growth rate of 2.2% producing an extra 3.2 million people per year to go with 147 million. Each new British consumer uses 45 times more fossil fuel than each new Bangladeshi, so

Christian Message	**Sustainability Approach**
Stewardship responsibility	Concern with environmental degradation
Integrity and renewal of creation consumption and production	Dematerialisation and informed
Loving my neighbour and the common good	Deliberative democracy
and participatory public debate	
Concern for future generations of global equality	Intergenerational criteria
Criticism of self-interest, greed and exploitation of wealth between less and more developed countries	Equitable distribution

Table 6.1: Christian principles and values that underpin sustainability

that the population growth in this country produces almost as much CO_2 emissions as the 54 times larger population growth of Bangladesh [Myers and Kent, 2004].

The combination of population growth and economic development is resulting in a class of new consumers in countries such as China, India, Brazil, Mexico and Russia and could result in the redrawing of the economic map of the world. In five years time it is estimated that new consumers alone in these countries could well number over 1bn and account for 20% of the world's purchasing power [Myers and Kent, 2004]. The drive to acquire is one of the innate drives that increased the survival prospects of our early human ancestors. It differs today only in the extent to which rational analysis plays a part in human choices. It presents a special challenge because it is not just immediate and inbuilt, it is insatiable. "How much is enough?" asks Burnham and Phelan [Burnham and Phelan, 2000]; "when it comes from our genes, the answer is as much as possible". Parallels exist in animal populations as in the repeated interactions between individuals in social insect populations such as ants that produce complex adaptive patterns when a food source is identified. Through positive feedback more and more are recruited to the site of food at increasing rates [Sumpter and Beekman, 2003]. Consumer behaviour provoked by the release of a pop star's latest CD immediately involves those who go out and buy it followed by collective action through recruitment; reinforcement of the number that perform such an activity can result in an exponential explosion of sales. Advertising and marketing experts have not been slow to exploit such activity linking sex and sexual imagery with the sale of products and processes so that consumption becomes iconic. Hence the use of expressions of sexual display that advertise potency, fertility, availability or other characteristics deemed desirable to the opposite sex (*e.g.* SUVs, super-yachts, designer garments, celebrity homes) and to gains in self-esteem relative to others by the acquisition of positional goods.

The dominant view of human behaviour emerging from studies in evolutionary adaptation and psychology is that the adoption of a sustainable lifestyle is countercultural and does not come naturally. Dawkins [Dawkins, 2001] argues that we will get little help from our genes because they are selfish and have made us what we are. Centuries before, the apostle Paul wrestled with the problem of self. While he understood that to change selfish behaviour was a tough assignment, Paul discovered that fundamental change was possible. The flash of blinding revelation that life could be lived differently came in his case from the recently crucified Jesus Christ whose life, death, resurrection and teaching transformed not only the direction of Paul's life and value system but that of others of his generation, and countless beyond. Nonetheless the challenge of selfish genes was never far away – "I do not understand what I do; for I don't do what I would like to do, but instead I do what I hate" (Romans 7:15).

Consumer behavioural traits can be interpreted as pathological and irrational even if they offer selective advantages. Psychological denial may also occur as an irrational failure to face up to health-threatening behaviour of obese consumers or to an impending potential disaster. Pollsters assessing people's attitude about the possibility of a dam bursting high above where they lived found that concern fell to zero the nearer you approached the dam, a phenomenon of individual psychological denial that seems likely to apply to group psychology [Diamond, 2005]. In the present context, any proposal for change concerning consumption and production must contend with self-serving behaviour and denial, and appeal instead to the importance of strengthening collectively those social and moral behaviours that influence consumption patterns and valuing the planet for our future happiness and that of generations to follow. In other words we need to distinguish between a singular view of consumption and production that reflects individualistic trends and selfish behaviour, and a normative position that addresses how should we behave for social and moral forms of consumption and production that enhance well-being.

Pursuit of Happiness

For most people, happiness is the main, if not the only, ultimate objective of life [Ng, 1997] and people these days place a lot of emphasis on it. There are two senses in which happiness can represent a state of people's well-being. The first and more traditional sense is about happiness as a one-dimensional hedonic expression of our feelings. It conveys the message that happiness is a transitory and subtle representation of our self-satisfaction with life. The second sense is about happiness as eudemonic expression of a fulfilling life. It conveys the message that happiness is achieved according to our life-long goals and sense of autonomy in our daily affairs of life. Nettle [Nettle, 2005] gives the example of the Greek philosopher Aristippus who, in the fourth century BC, held the view that the goal of life is to maximize the totality of one's pleasures, a pure form of hedonic utilitarianism worthy of Jeremy Bentham twenty-two centuries later. Three hundred years before Christ the Greek philosopher, Epicurus, said that happiness is man's greatest aim in life and that tranquility and rationality are the cornerstones of happiness. Today, Nicola Benedetti, BBC Young Musician of the Year at the age of 17 years released his first album. When interviewed about what he would like to achieve before he died replied – happiness and fulfilment - sentiments concerned with setting ourselves goals that stretch us [Layard, 2005]. Undoubtedly they imbue Nicola's life with purpose and direction and would resonate with the focus of the lifestyle of many people.

Attempts to measure quantitatively what gives us greatest happiness has proved difficult [Nettle, 2005] and many ingenious procedures have been applied. Subjective happiness expressed in pleasant affects such as elation, joy, contentment, and ecstasy has been measured by the use of physiological and neurobiological indicators, by observed social and nonverbal behaviour, and by person surveys. The big five factors in order of importance are family relationships, financial situation, work, community and friends, and health. Personal freedom and personal values also play a major part (see [Layard, 2005]) and new research claims that happiness can be lastingly increased [Seligman, 2002]. Satisfaction with life can also be influenced by our past and future as in the practical desire to upgrade one's house or move to another location, by how we think people view our lives, as well as by the goods we acquire. On the other hand unpleasant affects associated with guilt, shame, anxiety, worry, anger, stress, depression and envy are identified as common sources of greatest unhappiness that are to be avoided, accommodated or neutralised in some way.

People's material standard of living is regularly mentioned by a majority of respondents to surveys as being one of the most important elements of happiness (accepting that "all social science measures are imperfect", [Frey and Stutzer, 2002]). Annual surveys of more than 20,000 students entering colleges in the USA showed an increasing percentage that said it was very important to be very well off and a declining number saying that it was very important to develop a meaningful philosophy in life (see [Myers, 2002]). Nonetheless, rich people are only slightly happier than the less well off, as found in the USA where a simple correlation between happiness and income was only 0.2 (National Opinion Research Centre quoted in Easterlin 2000), and in Switzerland where the highest income recipients reported a lower well-being than the income group immediately below [Frey and Stutzer, 2002].

Clearly, there are many reasons why higher income and material prosperity do not simply translate into greater happiness. The most evident, perhaps, is that aggregated indicators of material well-being say very little about how higher income levels are distributed among different individuals and social groups. It is logically possible that income per capita grows with higher income concentration. Most importantly people compare themselves with others and their relative income is what becomes important. In addition, increasing per capita income does not raise individual well-being in the long run because aspiration levels adjust to the rise in income (hedonic treadmill effect); people get used to the higher income level which then produces less happiness for them than they would enjoy if no such adjustment had taken place. Lottery winners are very happy after winning but their happiness levels revert back near to the original level after some weeks. Television can be bad for happiness because of its negative impact on a person's perceived position in society and its influence on consumer behaviour. If we find ourselves watching television an extra hour a week it causes us to spend an extra £3 a week simply through responding to advertising that stimulates the desire rather than the need to buy goods and services to keep up with the "Joneses" (see [Layard, 2005]). Therefore, what is clear from happiness research is that the relationship between happiness and per capita income is not closely matched and across countries it is complex, though it is well established that people in rich countries are generally happier than those in poor countries [Frey and Stutzer, 2002].

The pursuit of happiness was of such importance to the founding fathers of the USA that they enshrined it in the Declaration of Independence as the right of all Americans. "We hold these truths to be self-evident that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty and the pursuit of Happiness" [Jefferson, 1776]. It is unsurprising, therefore, that the subject of happiness continues to feature heavily on the self-improvement shelves of every American bookstore and in every airport bookstore because it is central to American thinking. After all, many who were raised in the UK and then settled in the USA over 300 years ago had been brought up on the Westminster Catechism which posed the key question – what is the chief end of man? And the answer was – man's chief end is to glorify God and to enjoy him forever.

Many good reasons exist why Christians should be happy and why we should enjoy our faith in God through Jesus Christ. We praise God not primarily out of duty but out of enjoyment. There is evidence that people who believe in God are happier because they experience the discovery of the deepest and most enduring happiness in God, a eudemonic happiness that reaches its fulfilment when it is shared with others through its loving expression [Myers, 1992]. It is a natural part of worship, praise and virtue, and it is implicit in Paul's letters to Christians in Corinth ("whether you eat or drink or whatever you do, do it all to the glory of God"; 1 Corinthians 10:31) and Rome ("for from God and through him and to him are all things. To him be glory for ever"; Romans 11: 36). We have reason to be happy because biblical teaching helps us to understand the ground of faith, what we believe about God, what God has done to save us and win us for himself, how to test between truth and falsehood, the nature of our new value system, and the rules and guidelines for daily living (Colossians 3, 1-10). Furthermore, we should be happy because of faith in the future; as William Barclay put it: "From now on the Christian will see everything in the light and against the background of eternity... he will no longer live as if this world was all that mattered; he will see this world against the background of the large world of eternity". Yet, for Christians who live in the relatively prosperous first world, we have a faith to live while surrounded by conspicuous profligacy and abuse of the planet's resources. As Christians and consumers we are free either to choose the best way to pursue our lifestyle through a rational choice model, or we are locked into what Jackson [Jackson, 2005] calls a "social pathology" driven by social norms and advertising. If for most individuals happiness is the main, if not the only, ultimate objective of life, the question is whether our society has become seriously adrift because through consumer-driven acquisition of economic goods accompanied by damage to natural capital, we simultaneously degrade our own psychological and social well-being.

In this section we have seen that consumption, although necessary for human welfare, is not a sufficient requirement for happiness, and that prosperity gained at the expense of the habitability of the planet would be perverse. If unsustainable consumption has such a low impact on individuals' well-being, is there an alternative based on the Christian value system?

Towards a Christian Framework

The Christian message speaks of how God intends us to live and how we should construct and reconstruct the world and our lifestyles accordingly – in peace and harmony, in social justice, in humility and in faith. Today, the churches regard it as one of their prime tasks to cultivate a religious sense of humility and awe towards the natural world. The exploitative culture which it had been thought to mistakenly sanction has to be consciously replaced for the common good underpinning the far-reaching changes in lifestyle and culture that are urgently needed if the planet is to be saved for future generations [Longley, 2005]. The covenant that Yahweh made with the people of Israel after Adam and Eve were said to have been turned out of the fruitful and peaceable Garden of Eden promised, once again, a land which was close to paradise. It was a land flowing in milk and honey, rich in natural goods and fertility. As Murray [Murray, 1992] says, it was not limited to humans because it was in effect a "cosmic covenant" because it encompassed both the land and all its inhabitants within its embrace. It was a covenant that spoke of God's rescue of all creation and not just humankind. Yet once again self-interest, greed and exploitation asserted themselves as the Israelites became settled in the land and followed other gods, the rich appropriated the wealth of the land for themselves, the just laws of good governance were abandoned, and the poor and downtrodden sidelined. The land suffered, environmental degradation set in with its consequent effects on the inhabitants of the earth (Isaiah 5:8-10; 24:1-6), Abraham and his nephew, Lot, were forced to go their separate ways because the land could not support them and their families if they stayed together (Genesis 5:6), and in due course few men were left (Habbakuk 3:17). Jeremiah commenting on the Fertile Crescent of Mesopotamia spoke of declining fertility and desertification because of the over-use of irrigation leading to reduced soil quality, loss of vegetation and a change in the local climate (Jeremiah 18:14). Such passages, which are by no means isolated examples, reveal the disturbing connection between human injustice and the distorted distribution of wealth and the environmental exploitation and degradation of the created order [Northcott, 2001].

The linkage between the drive to consume and unsustainability has been examined in a recent analysis of the demise of flourishing cultures such as the ancient civilisations on Easter Island, the Native American civilizations of the Anasazi and the Maya, and the medieval Viking colony on Greenland [Diamond, 2005]. Diamond argued that their disappearance was linked to one or more, and in some instances, all of the following elements – resource depletion, unstable trading partnerships, galloping reproductive growth rates and the failure to respond to the tell-tale signals our environment gives us. "Failed states" in modern times display similar characteristics that have led to revolution, violent regime change, collapse of authority, and genocide played out in countries such as Burundi, Indonesia, Rwanda, Haiti, Iraq, Somalia and Afghanistan. However, some societies have survived when faced by similar problems (Iceland, the traditional caste societies of India, ranchers in Montana, and even members of the European Community). In these cases individual rights were subjugated to group interests even though such rights were fought for so dearly in earlier generations. By managing their shared resources they avoided the tragedy of the commons that had afflicted many and terminated cultures. The process of social reasoning and public discussion as well as observation and experience played their part in influencing values and operational norms negating any tendency to sign up to environmental determinism.

However, Dasgupta [Dasgupta, 2005] takes Diamond's analysis to task. As an economist he shares Diamond's worries, but think "he has failed to grasp both the way in which information about particular states of affairs gets transmitted (however imperfectly) in modern decentralised economies – via economic signals such as prices, demand, product quality and migration – and the way increases in the scarcity of resources can itself act to spur innovations that ease those scarcities. Without a sympathetic understanding of economic mechanisms, it isn't possible to offer advice on the interactions between nature and the human species". That is, people can help themselves and there is no reason why such a process should not happen with sustainable consumption and production even if the modern debate has an international dimension that demands global attention and not only local solutions [Northcott, 2001].

Hence, we see that failure to address the demands of sustainability threatens the created order as Pope Benedict XVI said in his inaugural address – "the external deserts in the world are growing, because the internal deserts have become so vast. Therefore the earth's treasures no longer serve to build God's garden for all to live in, but they have been made to serve the powers of exploitation and destruction". Inefficient production and resource overconsumption in more developed countries, the deprivation and degradation of communities due to underconsumption and the impact of hazardous waste of industrialised countries on the health of people living in the less developed countries are living proof of social injustice. We have noted how millions of tons of waste are transported each year to countries such as China (electronic waste). Industrial residues have been detected in people living in remote areas of the world such as East Greenland and Siberia among the Inuits (Eskimos), examples that testify to the alarming impact of our unsustainable practices on our distant neighbours [Diamond, 2005]. Moreover, disregard for intergenerational justice is tantamount to theft as in the behaviour of the thief who comes to steal, kill and destroy when Jesus clearly portrays that his redemptive mission is to bring freedom and to make it fully available (John 10:10).

Any Christian framework of sustainable consumption demands at its source the recognition of God as the creator and redeemer of all, revealed through the life, death and resurrection of Jesus Christ. As Paul wrote "[God] made known to us the mystery of his will according to his good pleasure that he set forth in Christ, as a plan for the fullness of time, to gather up all things in him, things in heaven and things on earth" (Ephesians 1:9-10). For early Christians, understanding Christ as the Redeemer was a challenging insight not only into his salvific relationship to humanity but of the deep meaning of his redemption of the created order and his countering of the expression of sin and evil in all their forms [Northcott, 2001]. The resurrection of Christ enunciated God's intention to restore the whole of creation for "in proclaiming the resurrection of Christ, the apostles proclaimed also the resurrection of mankind in Christ; and in proclaiming the resurrection of mankind they proclaimed the renewal of all creation with him" [O'Donovan, 1984]. We find here the framework of Christian values as they apply to the material and moral ordering of creation and its restoration based on righteousness and justice which are intrinsic to the being of God, the divine work of Christ and his continuing relationship with humankind.

Forrester [Forrester, 2001] points out that justice in the Bible is usually set in an eschatological framework as something we hope for and that is not fully realized here and now because it is currently provisional and relative compared with its full manifestation in the future.

Jesus demanded that Christians should seek first God's reign and his justice as something to which everyone is welcome but with a preferential invitation to the poor, the disadvantaged, the excluded and the marginalized (Matthew 6:33). Paul in a well-quoted phrase spoke dramatically of how the whole creation was groaning because it was caught in a downward spiral of decay "right up to the present time" and was awaiting release (Romans 8:22). None of this is an excuse for thinking that action can be delayed but rather that we should possess a deep passion for right-thinking, justice and care of the created order as beautifully portrayed by Bonaventura's essay on the life of Francis of Assisi. Francis delighted in all the works of God and "followed his Beloved everywhere by his likeness imprinted on creation loving compassion made him regard everything with affection but especially the souls which Jesus Christ redeemed with his precious blood" [Cousins, 1978]. Therefore, we are faced with the question "what does the Lord require of you?". The prophet Micah's response was that we should do justice and love kindness, and walk humbly with our God, "a fitting reminder that justice is something to be done, something that is inherently relational or social" [Forrester, 2001]. In terms of sustainability what practical form might a Christian response take?

Contents of a Blueprint

The main idea in this section is to outline a blueprint that could lead towards sustainable consumption and production embracing both our divinely-ordained role of Christian stewardship and our common desire for true happiness. The decline of religious belief and social solidarity in the last century and the rise in individualism and the progress of science has left us with two dominant ideas in more developed countries; Darwin's theory of evolution from which many have drawn the conclusion that you have to be selfish to survive, and the perception incorrectly attributed to Adam Smith of the "invisible hand" from which we learn that if everyone is completely selfish things will actually turn out for the best; "free contracts between independent agents will produce the greatest possible happiness" [Layard, 2005]. If the modern dilemma arising from the substantial evidence that the desire for happiness in peoples' lives is not guaranteed by an obsession with economic growth and unbridled consumption why not consider an alternative of greater promise? Yet, the future is notoriously difficult to predict though it can be invented. An ancient proverb reminds us that where there is no vision the people perish (Proverbs 29:18) and it was Henry Ford who used the art of visualization to start what became the second largest automobile company in the world. He created a mental blueprint of his dream car long before it was ever put to paper and pictured people buying and driving this low-priced car. The idea gradually became feasible and eventually a reality. A blueprint directed towards sustainable consumption offers a different approach to familiar themes; stewardship, responsibility, choices, injustices and intergenerational elements. It will be multidimensional and designed to engage Christians of all traditions and disciplines.

Those who fail to grasp the urgency of the situation should recall the Malthusian tragedy in Rwanda towards the end of the last century when 800,000 Tutsi's were killed (11% of the population) largely, but not exclusively, due to an inability to address the problems of unsustainability that stemmed from overpopulation. Genocide arose "because it provided a unique opportunity to settle scores, or to reshuffle land properties, even among Hutu villagers it is not rare, even today, to hear Rwandans argue that a war is necessary to wipe out an excess of population and to bring numbers into line with the available land resources" ([André and Platteau, 1998]; quoted by [Diamond, 2005]).
Even before Malthus, the French mathematician and Enlightenment thinker Condorcet [Condorcet, 1955] was expressing the hope that people will reason their way into achieving technical progress as well as behavioural adjustments. He wrote that "a very small amount of ground will be able to produce a great quantity of supplies of greater utility or higher quality; more goods will be obtained from a smaller outlay; the manufacture of articles will be achieved with less wastage in raw materials and will make better use of them". Neither Condorcet nor Malthus were able to perceive the remarkable impact of prospective scientific advances and, in particular, those in food production that would forestall widespread global famine. Nonetheless, Condorcet had the prescience and perspicacity to anticipate the role of sustainable consumption and production when life was different.

Definitions and objectives. Sustainable consumption lies at the heart of the concept of sustainable development and enriches our understanding of sustainable development because it emphasizes the need for consumption habits and attitudes to change. This need for change was highlighted by the USA National Academy of Sciences who recognized that without a reversal of present trends of consumption, production and environmental neglect "many human needs will not be met, life support systems will be dangerously degraded, and the number of hungry and poor will increase" (National Research Council 1999). Various attempts have been made to define the strategy and a working definition includes the following – "*decisions, influenced by ethical demands, promoting better quality of life and environmental sustainability*". The practical objectives of sustainable consumption are sweeping in their scope and intention; to reduce the consumption of natural resources by improvements in the efficiency of processes and services; to minimise the emissions of waste, pollutants and toxic materials over the life cycle of products, processes and services; to create new materials with long life, durability, and with re-use properties; to conserve biodiversity for current needs and freedoms; and to address disparities between more and less developed countries and protect the needs of future generations. In any case, a compromise is almost unavoidable between the technological and ethical dimensions of economic decisions in formulating a definition of sustainable consumption that is able to carry enough consensus for practical purposes.

The challenges of sustainable consumption and production can be examined under at least five headings that address how to consume differently and reduce our effect on the environment at the same time, the so-called "double dividend" [Jackson, 2005].

Science, engineering and technology. The writings of Rev. Thomas Malthus (1798) are frequently quoted for their pessimistic predictions about the demise of civilisation based on the observation that human population growth increases exponentially (because the extra people reproduce at a geometrical rate) and will outrun the growth of food production which increases only arithmetically (improvements are additive, not multiplicative). However, by 1803 Malthus had modified his pessimism. He wrote that "on the whole, therefore, though our future prospects respecting the mitigation of the evils arising from the principle of population may not be so bright as we could wish, yet they are far from being entirely disheartening, and by no means preclude that gradual and progressive improvement in human society... . And although we cannot expect that the virtue and happiness of mankind will keep pace with the brilliant career of physical discovery; yet, if we are not wanting to ourselves, we may confidently indulge the hope that, to no unimportant extent, they will be influenced by its progress and will partake in its success" (see [Smil, 2000, xxvii-xxviii]). Certain advances in science and technology have already steered us towards sustainable consumption almost inadvertently, some have been more successful than others, and many have been not been identified with this objective because it was not defined as the central goal or priority.

Dematerialisation has been a pervasive theme because it implies greater efficiencies in use, production and process. The production industries have used "green chemistry" to reduce energy and water consumption and decrease waste output in numerous sectors (chemicals, pulp and paper, textiles, food, energy, metals and minerals). Today's refrigerator-freezers in the UK consume on average 50% less energy than those sold just 8 years ago. The construction industry have built competitively-priced houses in London with electricity derived from a combined heat and power unit using wood taken from sustainable tree management in local streets and parks. Shared cars, low allergy building materials to minimise respiratory problems of residents, and recycling techniques to reduce waste by 80% have resulted in a carbon neutral project with a total saving in reducing the CO_2 footprint by 41% and with the long term objective of a zero-squared project consisting of zero waste and zero carbon emissions, a classic exemplar of dematerialization. In engineering, the ingenuity of its practitioners in the production and fabrication of useful artefacts and their distribution to the consumer has resulted in an S-shaped pattern of growth in the consumption of resources during the last century, namely, a lag period followed by exponential growth and then a plateau so that fewer materials are now used for a unit of production. Within the EU, manufacturers are required to recycle 85% of a vehicle's weight by 2005 rising to 95% by 2015. In food production, advances in plant breeding have resulted in new hybrid rice for Africa that has given over 50% more grain than current varieties when cultivated in traditional rainfed systems without the use of chemical fertilizers. Genetically modified crops also reduce the chemical burden on the environment and are safer for farmers who are exposed to lower levels of pesticides, and they diminish waste and pollution. In respect of biodiversity the Millennium Ecosystem Assessment [MA, 2005] makes for sober reading with some 60 per cent of the planet's ecosystem services already degraded by human activities through atmospheric pollution from excess greenhouse gases, draining of freshwater aquifers, overharvesting of forests and fisheries, contamination of oceans and introduction of alien species to new regions. As a result, 20 per cent of the world's coral reefs have been lost and 40 per cent of the planet's rivers fragmented. Science and technology are faced with the mounting challenge of reversing the impact of unsustainable consumption. At least the work of the MA has identified where we stand and advances have been made in determining the indicators that will be needed to monitor whether the path is one of progress or decline by establishing the minimum viable populations for sustainability.

We see that freedom exists in this sector to choose initiatives that will mitigate the negative impacts of consumption in more developed countries and provide for future global population growth in less developed countries. This freedom will not be sufficient in itself to overcome unsustainability because consumers' behaviour and lifestyles together with the response of businesses and industry will be crucial aspects of any solution. Whereas much work is needed to quantify the relative importance of technological "fixes" favoured by some and the adaptation of human behaviour to new phenomena such as damaged environments and exhausted resources, it is to consumer behaviour that we must now turn.

Consumption behaviour and lifestyle. Every man and woman has the right to prosper yet at the same time they have to recognize that others have the same right not only nationally but globally. This shift of consciousness has vast significance. The Christian Church has a commitment to social justice and to identify and oppose injustice and oppression, to stand alongside the marginalised and excluded, and to protect intergenerational interests as well as those of the present. Economic activity that leads to wealth creation is one of the chief engines of progress and greater well-being and one that we should celebrate. However, the pursuit of profit as an end in itself frequently results in hardship, injustice, and unsustainable consumption [Longley, 2005] though it is the conditions under which the profit is pursued that can lead to more or less income inequality.

People's lifestyle and consumption patterns are known to be affected by conscious decisions about the future of the planet. Hamilton [Hamilton, 2003a] believes that in a post-modern growth society much greater attention should be devoted to the way people think about their lives and relationships and he rejects an ideology and its social structures that are driven by growth fetish marketing. During the last decade 25% of British adults aged 30-59 have chosen to downshift in their lifestyles (rising to 30% if those stopping work to look after a baby or set up their own businesses are included). Downshifting was slightly more common among women than men, it was spread evenly across age groups and social grades, the average reduction in income was 40%, and the decision was taken not for the purpose of living closer to nature but because the excessive pursuit of money and materialism came at a substantial cost to people's lives and those of their families [Hamilton, 2003b].

Mathematical modelling has value in evaluating the complexities of such decision-making as well as the whole consumption process of purchase, use and disposal. A practical example from a hypothetical analysis of the impact of choosing to eat in restaurants instead of at home which has become fashionable in more developed countries illustrates some of the issues that need to be considered. It is claimed that the practice is more environmentally friendly because energy utilization in large kitchens is more efficient than in small ones. Based on data from Japan, if households decreased cooking at home by 10% and increased eating at restaurants the demand for eating and drinking places would go up by 1.49 times. The calculated environmental loads showed an increase in the total CO_2 emission of 0.30% (less sustainable) while landfill (waste) decreased by 0.30%(more sustainable). However, the effect of spending more time and money at restaurants meant less was available to spend on other forms of consumption so that when the "rebound effect" [Hertwich, 2005] was taken into account there was a significant reduction in emissions and landfill and the lifestyle change was overall more environmentally friendly [Takase, 2005]. Other examples are urgently sought to help us construct a persuasive evidence-based argument; this is essential if we believe that sustainable consumption and production should be taken seriously by consumers and policy-makers alike [Hertwich, 2005].

A freedom-based approach to sustainable consumption and production helps to limit the role of strong-armed imposition argues Amartya Sen [Sen, 2003]. If the chosen approach were to concentrate only on living standards rather than freedoms in general then the balance of policy instruments would more likely lean in the impositional direction. In the ecological context Sen considered the case of a deteriorating environment in which future generations are denied the opportunity to breathe fresh air because of dangerous emissions circumvented in future generations because their standard of living is so very high and well served by amenities that their overall standard of living is unaffected. Some may see no need to protest on the ground that the standard of living will be as high as the present one. But that overlooks the need for anti-emission policies that could help future generations to have the freedom to enjoy the fresh air that earlier generations enjoyed, a classic example of the need to address intergenerational and not only intragenerational demands. However, compulsion in the form of regulation may be needed to safeguard people's other freedoms including freedom from pollution or from deprivation, even in generations to follow.

Industrial and business practices. A purely negative approach to industrial and business practices is unacceptable because prosperity with a purpose is something to celebrate rather than to berate. When economic activity raises the standard of living of the population and relieves the distress of the poor it is a component of God's will for the common good. In this sense we thank God for the creation of wealth by economic activity as it is an important engine of progress and greater well-being in the modern age provided that it is coupled to suitable distribution of this wealth and brings benefit to the disadvantaged including less developed countries. Its effects include sufficiency of wealth in communities, pleasure and happiness, civilization and culture, and longevity including good health. Most co-operations in the private sector are keen to project themselves as good corporate citizens because if business conducts itself without a moral compass it will deplete the moral capital of the community. Small acts of selfishness, neglect or moral blindness in the industrial and business communities can sometimes be multiplied through the leverage of economic mechanisms until great harm is done with longstanding effects [Longley, 2005].

Business ethics and corporate social responsibility (CSR) have become part of management training and practice, and many believe that transformation of the relationship between business and living systems will dominate the new century in which we live (see [Hawken, 2000]; [McDonough and Braungart, 2002]). Others are more sceptical and consider that CSR has become an industry in its own right and that capitalism does not need the fundamental reform that many CSR advocates wish for [Crook, 2005]. Clearly, there is still some way to go before this idea has permeated widely but market campaign activity has motivated change exemplified in three case studies which show how non-governmental organizations (NGOs) have changed the habits of multinational companies. Staples, the number one retailer of paper and office supplies in the USA with annual sales of $11 bn per year, have agreed to phase out the sale of products made from endangered forests and achieve a minimum average of 30% post-consumer recycled content across paper products it sells. Nike, the number one merchandiser of sports shoes in the world with over $10 bn in annual sales has been targeted by a loosely co-ordinated campaign including Oxfam Community Aid Abroad, Hong Kong Christian Industrial Committee and United Students Against Sweatshops. The company has agreed to phase out toxic products in 10 years through green design and it is now the number one user of organic cotton for use in its garments, though it has still not agreed to pay a living wage to its workers. Dell is the largest seller of personal computers in the world and sells over $32 bn electronic products per annum. The Computer-Take-Back Campaign has forced the recycling of PCs and raised awareness of the e-waste problem [O'Rourke, 2005].

Transparency and accountability feature highly among the public priorities of today's industrial and business organizations. Historically, industrial practices underwent a remarkable change when it was discovered that chlorofluorocarbon (CFC) compounds can have dramatic effects in the stratosphere. CFCs are non-toxic, stable and inexpensive with low thermal conductivity and excellent for insulation in refrigerators and air conditioners. They evaporate and recondense at room temperatures but in the stratosphere they cause immense damage to the ozone layer and threaten human health [Rowland and Molina, 1994]. Political will was galvanized on an international scale, though the response time was about 26 years from scientific discovery to full implementation of the ban. Pressure from scientists and non-governmental organizations about the erosion of the ozone layer particularly over Antarctica led ultimately to the Montreal Agreement in 1987 and the London Agreement in 1990 aimed at phasing out the production of CFCs by 2000. Molina who shared the Nobel Prize in 1995 with Crutzen and Rowland said that when the United States prohibited the use of CFCs as propellants in spray cans experts believed the ban would put a lot of people out of work. It did not because effective alternatives were found. Nonetheless, it will take more than a century for the chlorine to be cleansed from the stratosphere [Meadows, Donella, 1995]. This example reminds us that consumers, and not just governments, have the ultimate responsibility for the behaviour of even the biggest businesses because businesses change when the public come to expect and demand different behaviour, or the public make things difficult for businesses practicing behaviours they no longer want because of different priorities. As a result manufacturers have discovered what is called lean consumption; this means insuring that all goods and services work, providing the customer with what s/he wants and where and when, and avoiding wasting the customers time [Womack and Jones, 2005]. Even the car industry is beginning to realise that people no longer look for the fastest possible acceleration, *e.g.* BMW, but the greatest fuel efficiency and the lowest possible gaseous emissions, as in the hybrid Toyota Prius. Cherished definitions such as “high performance vehicle” can change.

Fiscal measures. The desire for prosperity manifests itself in many diverse ways including the ability to choose freely what is truly good. Consumption is perceived as one expression of a prosperous society that wins votes at election time. Whether consumption can be taken to be good for us is another matter. As mentioned previously, we may see it as synonymous with improved well-being and the more we consume the better off we are, or we see its scale as environmentally and psychologically threatening to our quality of life [Jackson, 2005]. Arguments for a strategy of sustainable consumption and production will have to be accessible as well as persuasive and this is where it becomes important to know where the responsibility lies and what may be done about it by parents and professional teachers who have a fundamental role to ensure that the spiritual dimension is not ignored, as do the media and the tone they set, in addition to the legal system and the churches [Longley, 2005].

We are challenged by the example of the rich young man in the gospels who was too attached to his possessions to take up the offer of eternal life. Jesus made it clear to him that his obsession with possessions was the enemy of his true freedom in this life as well as the next. In any full sense he did not prosper since, as others have discovered, further affluence does not automatically lead to happiness, and often leads away from it. Hence, when the king of Bhutan made an enlightened announcement in 1998 that his nation's objective would be the Gross National Happiness, and a year later made the fateful decision to lift the ban that applied to television of the multichannel variety, there followed a sharp increase in family breakup, crime and drug taking [Layard, 2005]. Traditional economic measures such as the gross national product (GNP) used by UK's Treasury also lead to flawed decisions. GNP may be deeply engrained in political life as an assessment of a nation's economic progress and standing. However, a nation's capital assets can take several forms; they require measures of the net changes in manufactured and human capital, public knowledge, and natural capital. The indicator GDP is insensitive to the depreciation of capital assets and does not recognise the net value of changes in externalities such as the environment-resource base. As a result consumers are not presented with true costs. If wealth and social well-being are taken as equivalent it is possible that GNP can increase for a time even while the country becomes poorer and social well-being declines. As Dasgupta [Dasgupta, 2001] puts it – "the moral is banal: GNP is not a measure of the quality of life". If we were to get used to the term net national product (NNP) which has been proposed as an alternative it would represent a more realistic assessment of sustainable development by taking account and internalizing environmental costs [Dasgupta, 1998, Dasgupta, 2001].

The United Nations Development Index is another measure of well-being though neither this nor NNP are related to wealth, as shown in [Dasgupta, 2001]. A different approach has been reported in the USA where Daly and Cobb [Daly and Cobb, 1989] have developed an Index of Sustainable Economic Welfare (ISEW). This index adjusts the GNP, a personal consumption based measure, to account for a variety of social and environmental factors not generally included in measuring economic progress. The Yale Center for Environmental Law and Policy team has designed an Environmental Sustainability Index [ESI, 2005] for individual countries that measures their overall progress towards sustainability to provide and protect the environment for future generations. Others prefer measures such as the ecological rucksack (denotes the real burden carried by a product including costs invisible to the consumer), the ecological footprint (provides an equivalent value of land usage), or the environment space (reflects the freedom that is required to enable people to live in a certain way). The overall conclusion from all these studies is that no country could be said to be on a sustainable environmental path and that improved and transparent evaluations for each country envisaged by the ESI would focus attention on the environmental costs of modern lifestyles. Furthermore, fiscal measures such as perverse subsidies can exert adverse effects on both the economy and the environment. Their effects include the overloading of croplands leading to degradation, increased traffic congestion, the mis-use or over-use of water supplies, and the over-logging and over-harvesting leading to depletion of stocks. They are estimated at about $1.5 trillion globally [Myers and Kent, 2004]. Therefore, the accountability of policies directed towards sustainable consumption must demonstrate the true costs of modern consumptive lifestyles, their environmental impact, and the success or otherwise of fiscal measure such as subsidies. It is uncomfortable reading for most of us when we visit a global footprint website that provides entry into your personal ecological footprint (http://ecofootprint.org) and a visual gateway into the impact of our unsustainable consumption lifestyles, particularly if we consider that one of our chief functions is to be a co-worker with God in the continuous repair of the created order (which has the tendency to decay into disorganized systems), to bring new things into existence, and to establish new patterns of order (Romans 8:20). God's original creative work made order out of chaos, and our calling is to make more order yet, and to work creatively, and to co-operate with God's creativity as human beings made in the image of God. By making this increase in goods and services available to individuals and communities, we connect work and endeavour to wealth creation even before it connects with economic measurement, fiscal measures or socio-political systems.

Socio-political initiatives. Understandably, sustainable consumption has taken time to permeate into the political agenda because it has been seen to threaten the growth ethic of modern political systems with their prospect of unlimited economic growth. Will the day come when it will not be necessary to define or explain it? A recent survey showed that when people were asked about reducing consumption it was favoured by 60% of respondents in more developed countries, 50% in Eastern Europe and Russia, and only 30% in less developed countries in Asia and Latin America [Foundation, 2003]. Conferences can change perceptions and this has been progressively the case with consumption; the Earth Summit in 1992 (UN Conference on Environment and Development, UNCED), the UN Commission for Sustainable Development (1995), the UN General Assembly Special Session in 1997 (UNGASS), and the UN Department of Economic and Social Affairs in 1998 (UNDESA). The subject was demoted at the UN World Summit on Sustainable Development in Johannesburg 2002 (WSSD) demonstrating how reluctant we are to place consumption at the centre of discussions about sustainable development. A more promising sign comes from the formation of the Africa-led New Partnership for Africa's Development (NEPAD) that committed African countries to a "path of sustainable growth and development to halt marginalization of Africa in the globalization process and to enhance its full and beneficial integration in to the global economy". The link between economic globalization and the eradication of poverty was established earlier in India and China, but globalization has been largely adopted by the biggest players such as the USA and the European Union as a means to increase their economic strength rather than to put it at the centre of the global common good. As pointed out by Churches Together in Britain and Ireland [Longley, 2005] this position is totally unacceptable and one that Christians must challenge by their insistence on a greater share of national wealth being used for the relief of poverty and debt relief, accompanied by greater political dynamism in respect of trade liberalization and ecological sustainability globally since "economic growth is by itself no guarantee of an absence of conflict, either internally or between nations, and growth gained unjustly can be a great threat to peace".

Few of such documents, Christian or otherwise, aver to the central significance of sustainable consumption and production (SCP) in the interests of the common good, and this confirms that there is a long way to go before SCP becomes more than a mental blueprint. In the

UK a sign of encouragement is to be found in the Government's publication [HM-Government, 2005] entitled "Securing the Future" which details how departments are responding to the challenge of sustainable development. At least one, the Department for the Environment Food and Rural Affairs in the UK, has begun to amass an evidence-base and indicators to show how economic growth and environmental damage can be decoupled which will be essential if the argument is to move towards the centre of policy making [DEFRA, 2003]; [HM-Government, 2005]. Movement towards sustainable consumption and production demands a deeper understanding of God's promise to renew creation through Jesus Christ; of the application of our stewardship responsibility as depicted in the cosmic covenant; of justice as we address profligacy and poverty which are at the epicenter of ecological and sociological catastrophes; of equity that seeks to bridge the gaping divide between the more- and less-developed countries; and of the development of a blueprint from the rich source of Christian teaching.

7

The Influence of Scientific World View on Theology: a Brief Assessment and Future Perspectives

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Introduction

To the interrogation "Has the contemporary scientific world view any influence upon theology?", many seem to prefer to answer the negative. If science is said to have an impact on theological tenets, it is expected to challenge them or even to call them into question. For this reason, not to underline too much such an interaction is seen as a prudent, first-stage solution to the problem. Nevertheless, any believer knows that truth has a sound unity: the Word-Logos, by whom the world, object of the natural sciences, was created, and the Word which interprets and directs human history of salvation, are the same and one God. In his encyclical *Fides et ratio* (1998), John Paul II stated: "The unity of truth is a fundamental premise of human reasoning, as the principle of non-contradiction makes clear. Revelation renders this unity certain, showing that the God of creation is also the God of salvation history. It is the one and the same God who establishes and guarantees the intelligibility and reasonableness of the natural order of things upon which scientists confidently depend, and who reveals himself as the Father of our Lord Jesus Christ" (n. 34). When taking these words seriously, we are obliged to conclude that the effort to gain a true knowledge of nature, i.e. the task of science, has something meaningful to tell to theology.

However, if we want to investigate how might the natural sciences represent a helpful source of theological and even of dogmatic development, a couple of important issues must be clarified. The first one is to take a stand on the meaning of the truth of science; the second is to be ready to define more precisely, and even revise, some theological terms and categories, in the light of well established scientific results, that is, those results which look quite independent of any particular philosophical framework.

In relation to the first clarification, theology should not insist too much either on the fallibility of scientific enterprises – as if it were a necessary premise to dialogue – or on the supposedly utterly conventional nature of scientific knowledge, overemphasizing the complete equivalence and the continuous change of its interpretative models. Though these epistemological approaches may be partly justified, if we use them incorrectly we may end up averting scientific knowledge from its goals. This would confine science once again within the closed horizon of studying merely phenomena (*phainmenon*, that is, what appears), with the only task of safeguarding appearances, one which Copernican science had appropriately meant to move away from. Although the history of scientific thought has certainly not been producing a unified way of interpreting phenomena, and their links with the world of events made different readings possible, nonetheless, science as a whole could be reasonably understood as nothing but the gradual progression of abstract formulations towards the truth of things. Scientific knowledge, naturally feeding into philosophical reflection, also shares in that metaphysical effort that *Fides et ratio* identifies as the urgent need "to move from phenomenon to foundation" (n. 83). The world of experience is not a closed and self-referring courtyard, but it is the gate through which one enters in order to search for the essence of things. It may be significant to note, in this respect, that the document just cited mentions the acquisition of knowledge by empirical science in order to show –in analogy with philosophical thinking– that the search for truth is not genetically frustrated, but it is capable of resting on secure data: "This is what normally happens in scientific research. When scientists, following their own intuition, set out in search of the logical and verifiable explanation of a phenomenon, they are confident from the first that they will find an answer, and they do not give up in the face of setbacks. They do not judge their original intuition useless simply because they have not reached their goal; rightly enough they will say that they have not yet found a satisfactory answer" (n. 29).

In highlighting the search for truth within scientific research, and the real progress of its knowledge within a realist epistemological reference framework, superficial commonplaces such as the opposition between "how" and "why", or the insistence on the "limitations" of science, can be reduced in emphasis or even abandoned. Scientific research attempts to come up with answers to some definite "whys" and, within its specific formal object, it deals with an "unlimited" material object. It would not be difficult to show that even those limitations of which science becomes aware while reflecting on its own methodology (incompleteness, unpredictability, inadequacy of reductionism, need for holism, etc.) often result in "openings", *i.e.* transitional or transcending points towards higher levels of understanding, corresponding to more general formal objects. The path followed by Ludwig Wittgenstein in logic, regarding the need for transcending the language, is but one example of a conceptual itinerary reproducible also in other scientific domains. As a result, one should put more emphasis on reflecting on the "foundations" of scientific knowledge, rather than on its "limitations". Amongst the commonplaces to be discarded there is also the claim to solve complex issues in the debates between science and theology by affirming that a statement of science would not contradict Revelation because, in the end, we simply deal with "scientific hypotheses". This stems from an ambiguous as well as an incorrect epistemological view: in fact, if that particular statement of science is truly scientific, based on arguments developed in compliance with correct methodological procedures, we should expect that it by no means would contradict Revelation, even as hypothesis.

A second question concerns the use in theological discourse of terms with a strong cosmological connotation, such as earth, heaven, life, death, time, space, light, etc. In the Middle Ages, theology and science used the same terminology: nowadays this is no longer the case, and when this happens it is often cause for confusion. The very fact that theological, analogical, symbolic, poetic, and doxological languages, should necessarily be much richer than that of science, does not prevent theologians from seeking to be as linguistically accurate as possible, a requirement to which scientists are very sensitive. The use of two notions would call for special attention: those of transcendence and of experience. In treating the former, critical as it is to the entire theological discourse, theologians should be able to show at which level it operates with respect to the analysis of the sciences, and how it relates to the epistemological and anthropological openings of science itself; in the use of the latter, critical as it is to the entire scientific discourse, they should be able to explain in which way the experience of divine things and the experience of material things both intersect the sphere of the historical, sensible world.

To be convinced of how relevant this issue is, it would suffice to think how deep is the need to propose a language on God that may sound more meaningful to today's people, whose culture is shaped by scientific rationality[1]. The implications in the pastoral domain are obvious to all. As affirmed by the Assembly of Italian Bishops, "without valid reflections which may be capable of clarifying (and of articulating) the possible link existing between the historical path of humankind, the evolution of the universe and God's action in the world, any talk on God's reality and on his presence runs the risk of being culturally irrelevant and meaningless for life"[2]. Similar caveats are contained in other pastoral documents of the Roman Catholic Church, just as the one issued in 1999 by the Pontifical Council for Culture[3]. A few years have passed since the declaration of the former Secretariat for the Dialogue with Non-Believers, now Pontifical Council for Culture, pointed out that: "Christians do not consider science as a threat, but rather as a manifestation, at a deeper level, of God as Creator. On the other hand, scientific culture calls on Christians to mature in their faith, to be prepared to open up to the language and researches of scientists, and especially to use their discerning faculties *vis-à-vis* the technical applications of science"[4].

In more general terms, an approach capable of accepting the "challenge" posed by science to theology appears to be more demanding. To merely assert the compatibility between the scientific reading of the world and the reading of the world offered by Revelation, theologians might yield to the easy solution of considering science and theology as two completely separated realms, and so they need not to take scientific results quite seriously. If, on the contrary, they wish to use those same results as a positive source of speculative reflection and dogmatic development, they must do exactly the opposite by taking science seriously.

[1] Cf. Vatican II Council, *Gaudium et spes*, n. 5

[2] Italian Conference OF Bishops, *Tre Proposte per la ricerca*, 1999, n. 35; cf. nn. 27-37.

[3] Cf. *Toward a Pastoral Approach to Culture*, 23.5.1999, n. 35.

[4] "Atheism and Dialogue", 16 (1981), p. 231.

The Usage of Natural Sciences in Theological Work: a Brief Status Quaestionis

Generally speaking, both theological thought and the Church's Magisterium have paid less attention to natural sciences than to the humanities. The greater weight attributed to the latter is due both to their role as auxiliary sciences in the study and the interpretation of Holy Scripture (history, philology, etc.), and as sciences appropriate to the study of the historical and existential dimensions of the addressee of the Gospel message, that is of the human being (psychology, sociology, anthropology, etc.). Recent examples of the minor attention paid to the natural sciences are the absence of any references to them both in the Vatican II Constitution *Dei Verbum* (1965), devoted to divine Revelation, and in the Document of the PBC *The Interpretation of the Bible in the Church* (1993). If we look further back, Pope Leo XIII's encyclical letter, *Providentissimus Deus* (1893), suitably recognizes that "knowledge of the natural sciences will be of great help to the teacher of Sacred Scripture", although the main goal of this knowledge seems to be to define the areas of their competence, rather than foster the use of scientific results; a few lines further, in fact, that document adds: "Knowledge of the natural sciences will be of great help to the teacher of Sacred Scripture. Indeed there should be no real disagreement between the theologian and the physicist, provided that each confines himself within his own territory, watching out for this, according to St. Augustine's warning, not to make rash assertions, and to declare the unknown a known" *(incognitum pro cognito)* (DH 3287). However, an important assumption that would have later justified the idea of a positive contribution of the natural sciences to theology was contained, in a nutshell, in the document *Dei Filius* (1870) of the Vatican I Council, when it speaks of the "mutual help" to be granted by reason and faith in the understanding of dogmas (cf. DH 3019).

a) How theologians look at the sciences. One may well wonder why theological textbooks over the last 30 or 40 years have been so prudent and rather quiet on this issue. Eloquently silent was the book series *Mysterium salutis*, which meant to identify the main lines of theological renewal from Vatican II onwards [Feiner and Löhrer, 1976]. Up to the 1980s, textbooks on Creation or on Theological Anthropology containing links with natural sciences were very rare. Usually, they addressed these issues in a cursory and imprecise fashion, almost as if treading on a minefield. The gradual rise of interest witnessed at the close of the 20th century was mainly spurred by reflections on the ecological crisis and by the renewed focus on classical borderline issues known as the "problems of the origins" (of cosmos, of man, of life) with an annex concerning the final scenarios (future of humankind and of the cosmos). However, most of the reflections offered by theologians were only a response to scientists' works which had had such a remarkable philosophical impact on culture and on public opinion, that theology was bound to take them into account.

Among contemporary theologians, however, the work of Karl Rahner (1904-1984) and Wolfhart Pannenberg (born 1928) should be remembered as an example of theology which seems to have taken natural sciences seriously. Rahner left several remarks on this issue in the form of short essays. However, in these works he did not construct any structured proposal[5]. In his extensive monographs devoted to the present issue (Cf. [Pannnenberg, 1973, Pannnenberg, 1975, Pannnenberg, 1993]), as well as in a number of scattered articles, Pannenberg has developed a significant philosophical reflection in dialogue with science, especially in his *Systematic Theology*[6]. In Pannenberg's works a strong idealist philosophical viewpoint is present, which, by orientering the issue of truth on the far escathon, ultimately affects, at least in some ways, the consistency of his reading of the work of science. Alongside these two authors it is worth mentioning Thomas F. Torrance (born 1913), whose philosophical-theological production has copiously touched on the links between theology and science (Cf. [Torrance, 1989, Torrance, 1997]), and theologians such as Juan Luis Ruiz de la Pea, Karl Heim and Jrgen Moltmann. The latter has written a treatise on Creation containing interesting points for a dialogue with science [Moltmann, 1985], but instead of considering the influence of scientific data upon theology, he seems to be more interested in the analogies that some scientific theory (such as field theory) may offer, he argues, for an understanding of the relationship between God (the Spirit in particular) and the world. Some of his results look still largely unsatisfactory. Finally, we should not forget the contribution made by Bernard Lonergan (1904-1984), whose further philosophical insights originally grew out of questions about theological method (Cf. [Lonergan, 1957, Lonergan, 1972]). Here we have only mentioned scholars whose main working area is theology. In our view, they differ from the far greater number of authors who now devote themselves primarily to the relationship between theology and science, but whose standpoint is basically epistemology and not dogmatic theol-

[5]Some seminal remarks can be found in [Rahner, 1981].
[6][Pannenberg, 1991], cf. ch. VII: The Creation of the World.

ogy.

The case of the French Jesuit scientist Pierre Teilhard de Chardin (1881-1955) is certainly uncommon, but worthy of particular attention. Teilhard was not a theologian, nor did he use the natural sciences within a systematic theological project. However, his thought has greatly influenced and still influences theology[7]. Admittedly with some uncertainties and ambiguities, he is indeed the first author who tried to reconsider the results of science – particularly the evolutionary path of the cosmos and of life – in the light of Biblical Revelation, while offering original interpretations with implications on a much wider scale than expected. His reading of the relationship between Christ, the human being and the cosmos, inspired by his observations as a palaeontologist, and by his vibrant, and at times mystical reflections as a believer, has become a sort of model framework within which some theologians ended up interpreting central issues, such as the relationship between nature and grace or that between creation and redemption. However, if judged as a theological project, Teilhard's thought does not offer fully convincing solutions regarding issues of paramount importance for Christian doctrine, such as the understanding of original sin or the ways in which God is present in the cosmos. Thus, it may lead to conclusions that, in some specific respects, might differ from the teachings of Revelation.

A bird's eye view of 20th-century theology as a whole, except for some rare exceptions, would lead us to conclude that no particularly productive dialogue with scientific thought ever took place. We are thinking of a kind of dialogue that was not to be confined to marking boundaries or to clarifying errors, but one that would manage to use, in a careful but fruitful manner, some of the results and the new perspectives that 20th-century scientific research was able to hand over to the world of learning as a whole. The philosophical charge attached to these results was reflected in the wide-ranging debates spurred by science amongst philosophers, rather than amongst theologians. These debates, however, mainly focused on epistemological aspects, only seldom affecting anthropological or existential considerations, which, paradoxically, are likely to be present more in scientific than in philosophical works. The causes of the delay of theology are historically complex, but among them there is certainly the gradual loss of its "academic room". This stemmed from the fact that theology itself abandoned (sometimes unwillingly) university campuses in a number of countries of Christian Catholic traditions and remained confined to seminaries and to Pontif-

[7] For a concise review of his impact, cf. [Ratourelle, 1994].

ical universities. Moreover, important scientific subjects were excluded from syllabuses in the training of the clergy and more generally from philosophical-theological studies. Although the development of the natural sciences in our times has resulted in an expansion of knowledge that is no longer comparable with 19th-century learning, the presence of subject matters such as physics, astronomy, logic or biology, in the *ratio studiorum* of 19th-century seminaries, showed at least a kind of sensitivity that later would fade away. Such a state of affairs has contributed to increase the cultural gap between theological reflection and scientific reasoning that had slowly (and yet inexorably) been felt in early modern times. Quantitative evidence, for those who love data, is provided by a simple analysis of the scientific biographies contained in the monumental *Dictionary of Scientific Biographies* [Gillispie, 1970], it turns out that the percentage of scientists that were also secular or regular clerics of Christian Churches still covered in the 18th century 30% of all recorded biographies, but these dramatically plummeted to 10% in the early 19th century, before being reduced to very few personages in the 20th century. Although this data is no proof of the "efficiency" of the dialogue between theology and science –as the personages in question were merely scientists who were clergy but not theologians at the same time– it still provide an important indication of how scholars who were trained first in philosophy and theology, later on, decided to dedicate themselves to the study of various fields of science as professionals familiar with research and experimental science.

Of these authors it is worth mentioning Antonio Stoppani (1824-1891), a priest and a geologist, whose case is particularly interesting from a historical point of view. He was the first to produce a complete geological survey of the Italian territory (*Il Bel Paese*, 1875 – "Our Beautiful Country") and combined his scientific production with very attentive apologetic work, as well with a lively and more mature concern for the formation of the clergy in the area of the natural sciences. Despite its misleading title, in his work *Il dogma e le scienze positive, ossia la missione apologetica del clero nel moderno conflitto tra la ragione e la fede* [Stoppani, 1886], that is, "Dogma and positive science, or the clergy's apologetic mission in the modern conflict between reason and faith", he does not present an instrumental view of science as ancillary to a naïve concordist or a kind of polemical apologetics. Though allowing the constraints of the rhetorical discourse of the time, he offers, rather, a precise methodological vision: "to clarify the errors of science by science itself". By that he meant to stress the need for the clergy to attain a more profound competence in science, in order not to avoid or to underestimate the issues in question, but to tackle them with competence and provide a better service to theology. Some titles of the chapters in this work, such as "Condizioni speciali del moderno conflitto tra la scienza e il dogma e conseguente necessit degli studi naturali" (Special conditions of the modern conflict between science and dogma and subsequent need for natural studies, [Stoppani, 1886, 48-75]) or "Come lo studio delle scienze fisiche e naturali sia per l'universalità del clero cattolico specialmente indicato" ("How the study of physical and natural sciences should be particularly suitable for the whole of the Catholic clergy" [Stoppani, 1886, 227-236]), show by themselves what kind of project this scholar was pursuing.

b) The intellectual endeavor carried out by Thomas Aquinas. It is no idle exercise, in the present study, to look back at an even more distant past to find an instructive model in the work of Thomas Aquinas (1224-1274). It is commonly held among historians that, although he did not directly have a hand in the development of experimental sciences, he contributed to raise renewed interest in the study of nature by circulating Aristotle in Western Christian universities, and facilitated the introduction of much scientific knowledge of the time into theological thinking. The Papal encyclicals *Aeterni Patris* (1879) and *Fides et ratio* (1998), do not fail to single out Aquinas as a model for scholars and an expert of the scientific learning of his time, who, by his wise discernment, was able to start a constructive and fruitful dialogue where others had only seen obstacles or complications.

A fresh appreciation of Thomas Aquinas's method and spirit may therefore turn out to be useful for the current renewal of a theological approach to scientific learning, in spite of the gap separating us from the historical context in which he lived and worked. A recommendation by Pope John Paul II is no doubt explicit in this respect: "Contemporary developments in science challenge theology far more deeply than did the introduction of Aristotle into Western Europe in the thirteenth century. Yet these developments also offer to theology a potentially important resource. Just as Aristotelian philosophy, through the ministry of such great scholars as St. Thomas Aquinas, ultimately came to shape some of the most profound expressions of theological doctrine, so can we not hope that the sciences of today, along with all forms of human knowing, may invigorate and inform those parts of the theological enterprise that bear on the relation of nature, humanity and God?" [John-Paul-II, 1988]. (Original English text in L'Osservatore Romano, October, 26, 1988).

These are no isolated remarks. The same idea was authoritatively taken up, as hinted above, in the encyclical letter *Fides et ratio*, which presents St. Thomas as a "searcher for truth", wherever it might be found and by whomsoever it was studied and taught. Recalling a passage by Paul VI in his letter *Lumen ecclesiae* (1974), John Paul II writes: "Thomas possessed supremely the courage of the truth, a freedom of spirit in confronting new problems, the intellectual honesty of those who allow Christianity to be contaminated neither by secular philosophy nor by a prejudiced rejection of it. He passed therefore into the history of Christian thought as a pioneer of the new path of philosophy and universal culture. The key point and almost the kernel of the solution which, with all the brilliance of his prophetic intuition, he gave to the new encounter of faith and reason was a reconciliation between the secularity of the world and the radicality of the Gospel, thus avoiding the unnatural tendency to negate the world and its values while at the same time keeping faith with the supreme and inexorable demands of the supernatural order" (*Fides et ratio*, 43). And, also: "Profoundly convinced that 'whatever its source, truth is of the Holy Spirit' (*omne verum a quocumque dicatur a Spiritu Sancto est – Summa Theologiae*, I-II, q. 109, a. 1, ad $1^{u}m$) Saint Thomas was impartial in his love of truth. He sought truth wherever it might be found and gave consummate demonstration of its universality" (*ibidem*, 44). The aim of such exhortations does not (or does not simply) seem to be a laudative celebration of Aquinas's thought, but they are also meant as an invitation to accomplish in our time what St. Thomas did in his life. It is easy to see that nowadays such an endeavor would involve not only philosophical knowledge, but also that derived from the natural sciences.

c) The spirit of the Second Vatican Council and its further application. The poverty of explicit references to the natural sciences in the Church's 20th-century Magisterium, in sharp contrast with its developments concerning philosophy and the humanities, should not lead theologians to pay less attention to science in their work. In line with what we cited above regarding Thomas Aquinas' model, we may trace promising hints in some documents of the Second Vatican Council which, in their "spirit", perhaps more than in the "letter", would seem to encourage scholars to move in this direction. It was a specific intention of the Council, as is well known, to urge to present the Gospel message in a way that would better suit men and women of our times, in the awareness that "the experience of past ages, the progress of the sciences, and the treasures hidden in the various forms of human culture, by all of which the nature of man himself is more clearly revealed and new roads to truth are opened, these profit the Church, too" [VI, 1965, 44]. This and other passages that mention sciences add no explanation concerning the ways in which they may contribute to theology. Yet some passages by the Council's Fathers deserve a special attention.

Gaudium et spes contains significant references to the sciences in various places. Having recognised that the study of various disciplines, such as philosophy, history, mathematics and the natural sciences, contributes to raise the cultural and social conditions of humanity, and having called to mind that the progress of the sciences and of technology can promote a kind of phenomenism and agnosticism when their method is exalted as the supreme norm to search for global truth, the text points out that "those unfortunate results, however, do not necessarily follow from the culture of today, nor should they lead us into the temptation of not acknowledging its positive values. Among these values are included: scientific study and fidelity toward truth in scientific inquiries, the necessity of working together with others in technical groups, a sense of international solidarity..." (*ibidem*, 57). Taking into due consideration potential temptations and sometimes real misconceptions, the positive appreciation of scientific learning that also engages theologians in a fruitful dialogue with the world, may be deduced from the contents of another passage: "The recent studies and findings of science, history and philosophy raise new questions which effect life and which demand new theological investigations. Furthermore, theologians, within the requirements and methods proper to theology, are invited to seek continually for more suitable ways of communicating doctrine to the men of their times; for the deposit of Faith or the truths are one thing and the manner in which they are enunciated, in the same meaning and understanding, is another" (*ibidem*, 62).

Echoing what Pius XI had already written in his Constitution on the formation of the clergy, *Scientiarum Dominus* (1931), namely that the Catholic religion has to dread ignorance of truth more than any other enemies (*id unum timet: veritatis ignorantia*), the Second Vatican Council's decree on the formation of priests, *Optatam totius*, underlines the need for candidates to the priesthood to possess an adequate formation in the humanities and the sciences as a condition to enter higher education (cf. n. 13). In fact, for an in-depth study of theology account should also be taken of the more recent progress of the sciences. The net result should be that the students, correctly understanding the characteristics of the contemporary mind, will be duly prepared for dialogue with men of their time (n. 15). Finally, in the declaration *Gravissimum* *educationis*, it is stated that Catholic universities and theological schools of Church universities, shall promote closer co-operation with other centers of teaching devoted to scientific research (cf. nn. 10-12).

And yet it is in the teachings of John Paul II, often given in the form of addresses to the world of academia and of learning, that we find a kind of synthesis of the "spirit" of the Second Vatican Council, and a genuine development of its exhortations. Although he has not left any specific legislative indications –the Constitution on the reform of ecclesiastical studies, *Sapientia christiana* (1979) contained no indications as to the role of the natural sciences– there is no doubt that the whole of his long pontificate, and the sincere concern he has been showing towards the world of science as witnessed by his courageous and unprecedented statements, have been radically and positively reshaping the Church's attitude in this area. A further quotation from the already mentioned *Letter to the Director of the Vatican Observatory* [John-Paul-II, 1988] will suffice: "If the cosmologies of the ancient Near Eastern world could be purified and assimilated into the first chapters of Genesis, might contemporary cosmology have something to offer to our reflections upon creation? Does an evolutionary perspective bring any light to bear upon theological anthropology, the meaning of the human person as the *imago Dei*, the problem of Christology – and even upon the development of doctrine itself? What, if any, are the eschatological implications of contemporary cosmology, especially in light of the vast future of our universe? [...] Questions of this kind can be suggested in abundance. Pursuing them further would require the sort of intense dialogue with contemporary science that has, on the whole, been lacking among those engaged in theological research and teaching". In contrast with what may have happened in other periods of Church's history, this seems to suggest that we are living in a time when the Church's Magisterium indicates guidelines which anticipate theological research, and indicate a road that theology still seems unprepared to proceed along.

Bearing in mind the present context and the need of "translating" Aquinas' observations into a language capable of including the contemporary sciences as we now know them, it is interesting to re-read what he stated in the opening of Book II of the *Summa Contra Gentiles*. In that section he comes to the lucid conclusion that "it is therefore evident that the consideration of creatures has its part to play in building the Christian faith". Here we refer to some of the most illuminating excerpts: "The meditation on divine works is indeed necessary for instruction of faith in God. First, because meditation on His works enables us to admire and reflect upon His wisdom. For things made by art are representative of the art itself, being made in the likeness of the art. [...] Secondly this consideration [of God's works] leads to admiration of God's sublime power, and consequently inspires in men's hearts reverence for God. For the power of the worker is necessarily understood to transcend the things made. And so it is said: "If they", namely the philosophers, "admired their power and effects", namely of the heavens, stars and elements of the world, "let them understand that He that made them is mightier than they" (Wis 13,4). [...] Thirdly, this consideration incites the souls of men to the love of God's goodness. [...] Fourthly, this consideration endows men with a certain likeness to God's perfection. For it was shown in Book I that, by knowing Himself, God beholds all other things in Himself. Since, then, the Christian faith teaches man principally about God and makes him know creatures by the light of divine revelation, there arises in man a certain likeness to God's wisdom. [...] It is therefore evident that the consideration of creatures has its part to play in building the Christian faith" [Aquinas, 1995].

A little further, Aquinas' argument seems to involve even more directly the realm of "natural philosophy", when he claims that a careful knowledge of creatures helps avoid making mistakes concerning the knowledge of God: "The consideration of creatures is further necessary, not only for the building up of truth, but also for the destruction of errors. For errors about creatures sometimes lead one astray from the truth of faith, so far as the errors are inconsistent with true knowledge of God. Now, this happens in many ways. First, because through ignorance of the nature of creatures men are sometimes so far perverted as to set up as the first cause, as if it were God, that which can only receive its being from something else; for they think that nothing exists beyond the realm of visible creatures. [...] Secondly, because they attribute to certain creatures that which belongs only to God. This also results from error concerning creatures. For what is incompatible with a thing's nature is not ascribed to it except through ignorance of its nature [...]. Thirdly, because through ignorance of the creature's nature something is subtracted from God's power in its working upon creatures. [...] Fourthly, because man, who by faith is led to God as his last end, through ignorance of the nature of things, and consequently of his own position in the universe, believes that he is subject to other creatures to which he is in fact superior. Such is evidently the case with those who subject human wills to the stars" (*ibidem*, Book II, ch. 3). These remarks require no further comments. The conclusion St. Thomas comes to, linking up with Augustine and through him with the great tradition that preceded him, is still relevant nowadays: "It is, therefore, evident that the opinion is false of those who asserted that it made no difference to the truth of the faith what any one holds about creatures, so long as one thinks rightly about God, as Augustine tells us in his book *On the Origin of the Soul* [IV, 4]. For error concerning creatures, by subjecting them to causes other than God, spills over into false opinion about God, and takes men's minds away from Him, to whom faith seeks to lead them" (*ibidem*).

The Scientific Image of the World and its Main Implications for the Theological Understanding of Biblical Revelation

A number of results achieved by contemporary science should by no means be ignored by theologians. Indeed, these results represent a new source of knowledge that theologians have to take into account in their research. Based on these results, they can suggest, or at times even require, some new interpretations of Holy Scripture. Though the dogmatic content and the genuine meaning of what is revealed by God do not depend, as such, on the results of science, nevertheless the understanding of the Word of God may be advanced through them. This might even result in a better clarification of the internal coherence of Revelation and in an illumination on some implications for the faith. The general and abridged synthesis we offer here of some of the most important scientific results, whose widespread popularization let them become part of the "shared scientific knowledge of our times", saves us from providing point-by-point bibliographical references. Confining our analysis to the natural sciences, the theological areas mainly concerned by our topic are: fundamental theology, the treatise on creation, theological anthropology, eschatology, and to a certain extent Christology too.

a) A brief overall outlook on our more recent scientific achievements. As is well known, one of the most inspiring "expanding horizons" comes from physical cosmology. We now have sufficient data to conclude that the physical universe possesses a huge evolutionary and historical dimension. It has undergone a slow and continuous development over time, starting from an initial phase capable of "containing", in physical conditions of extremely high density and temperature and of incredibly limited size, all the matter and energy currently in existence. We cannot rule out that the universe may coexist with other space-time independent domains, totally separate from one another and having different evolutionary histories, urging us to better qualify and distinguish between a "physical" and a "philosophical" definition of the universe. The space-time horizon that lies behind our understanding of the universe in which we live has been extraordinarily widened, necessarily leading to a space-time re-setting of humankind and its cosmic *habitat*. Such "re-setting" implies a new physical and temporal context we can no longer ignore, just as, in the past, we could not ignore the new worlds reached by great geographic discoveries or the new cosmological assessment originated by the Copernican revolution. The time spanning from the formation of the first chemical elements to the appearance of life on earth, and from the rise of its most elementary forms to the appearance of humans, was incredibly long, much longer than could be expected even one century ago. Within their specific object and methodology, the natural sciences have been capable of tracing back without any interruption the key steps of that history, and they are able to predict some of its principal future scenarios. The latter also are characterized by very long, but not infinite time spans, enough to tell us that the conditions suited to host life are placed within suitable "time windows", that could not arise before a specific cosmic age, and that from a certain time onward will no longer arise.

But the wide spaces and great time spans involved, far from being redundant, have been strictly necessary to produce the conditions, places and times allowing for the slow synthesis of chemical elements and the subsequent formation of the physical scenarios and biological niches suitable to host life. Besides, we know that there is a delicate "primeval fine tuning" of the physical structure of the universe, and of the physical, chemical, and biological conditions on which life –due to appear very much later– would then be based. Today we know that for the appearance of human life *here and now*, the initial conditions of the cosmos have been as important as (and in some ways much more important than) the innumerable, contingent cosmic and biological events, which have taken place throughout the evolutionary history of the universe.

As regards to the laws governing the universe, we know that the physical universe is not always governed by laws that may be mathematically formalized and wholly predictable. The universe is not deterministic nor "undetermined": its basic components possess specific and stable properties, showing qualities of identity and universality on a large cosmic scale. However, besides "entities", the universe is made up, above all, of "relations", that often determine many elementary cosmic properties. In the physical universe nothing is totally isolated, because the nature of any part depends on the history of the whole. In the universe there is a positive quantity of information, which is non-reducible to the support of matter or energy through which information itself is conveyed. Above the whole scenario of the laws of nature, the question of the origin of their intelligibility and rationality emerges, as well as that of their accordance with our processes of knowledge. Again, as far as cosmic structure is concerned, we know that distinctions between matter and energy, space and time, matter and void, have to be reinterpreted through totally new categories: matter and energy can mutually transform each other; the flow of time depends on the curving of space, hence on the matter contained in it; physical void, once the universe exists, houses very high energies which may in turn be transformed into huge quantities of matter. Nature is truly capable of emergence and novelty. Her history is not merely that of slow and gradual decay towards uniformity: conceding that this holds true on a very large scale, on a small and intermediate scale new and more complex structures may arise, in which information is accumulated and grows. Physical reality remains something truly "open" to the novelty of history.

Biology, for its part, has shown that the human body is like a summary of the long history of the cosmos and of our planet. Most of the information essential for the bodily development of each individual is contained within a tiny genetic code, shared to a very large extent with inferior animal species. Genetic code can be seen as a kind of "program", capable of reconstructing, in a non-reductive but informational fashion, the physical and biological structure of the living being, and the various biological processes which control its life and development. Today we know that the different forms of life on our planet have undergone slow changes leading to the appearance of new species and to the disappearance of others. Such a long, temporal path not only displays a development or a growth, but also a real evolution. Various factors have contributed, and partly still contribute, in uneven ways, to make that evolution possible: the adaptation of living beings to the different environments in which they had to survive, some sort of natural selection, the development of precise organismic functions, the existence of internal processes, which, through their gradual emergence seem to have progressively channelled living beings towards more complex and perfected forms. It belongs to common and also to scientific experience that, among all these species, *homo sapiens sapiens* stands as a climax, a unique and singular case of a living being whose phenomenology cannot be entirely reduced to the biological panorama surrounding it, though being itself a part of it. The times and the ages that have marked the appearance of the human being on earth and, the gradual ascent of the first humans towards the achievements of civilization and learning, have been much longer than expected; it is much more distant in the past than we could have reasonably imagined only a few decades ago. Contemporary astronomical observations outside the earth's atmosphere have revealed to us that the presence of stars with planets around them is a relatively widespread phenomenon: no other forms of life, even basic ones, have been observed, but the hypothesis that these may have developed in environments similar to ours is quite plausible. Finally, it is scientific research again that teaches us that owing to the size of the universe, and on the basis of the time scales involved when communicating through space, it is not possible (nor will it ever be) to acquire complete information from all regions of the universe in order to check the potential presence of other intelligent beings: it is thus a possibility which cannot be invalidated on the basis of a priori arguments.

b) Room for a theology of science and a theology of nature. The sketchy list of results and perspectives drawn up above could have been even longer. We insisted on the results pertaining to the cosmological domain, and, to a lesser extent, on the challenges coming from biology or physical anthropology; we could have added other results, having a similar philosophical relevance, from the field of high energy physics, of quantum mechanics, of chemistry or biochemistry, of zoology or of human physiology. Contemporary results of mathematical sciences and logic, which also have a considerable philosophical bearing, may be considered as coming from the domain of philosophy, rather than from the natural sciences. Our concern, however, is not to supply here a thorough and in-depth list of results: what is at stake is to evaluate whether such results are solely a source of "trouble" for that interpretation of the world and human history, along with their relationships with God, that theologians make on the basis of Revelation; or, rather, whether the lessons we are taught today by the natural sciences may be a positive source of theological progress. True progress, yet, is only feasible when, in the event of problems, these are tackled and possibly solved by proposing new ways of understanding. And a better understanding of divine Revelation, while increasing its intelligibility, enhances the credibility of the faith in a scientific context as well.

On the positive balance, it suffices to note, for example, that today science provides theology with a much wider framework to understand actually what it means "to be a creature in a created world". It is the very meaning of terms as creature and world that gains today a weight and a context they did not possess before. If, of course, this does not directly enhance the dogmatic content of the theological notion of Creation understood as an act *ex parte Dei*, it certainly enhances it with respect to the implications of creation when understood as a relation and as a created effect. Again in the realm of the theology of Creation, it is not without interest to note that the essential conditions of the fine tuning of those physical and biological conditions on which the universe would be in due time built up, arose in the very beginning of the development of the cosmos, well before its subsequent long-term biological evolution. Greater emphasis ought to be placed also on the potential Christological resonances of the teleological, and no longer geometrical, centrality of life and of the human being within the cosmos. Perhaps, even the Christian doctrine of the resurrection of the flesh might profit from the acquired knowledge of what genetic information actually is, having in mind the inevitable dissolution of the human body. Would those Christian thinkers that pay so much attention to the "theology of the body", a body sharing in the image of God, capable of revealing the personal dimension of the subject and of being the temple of the Holy Spirit, simply be confused or would they rather be enlightened by the fact that such a body, even before being "human", encloses a very long evolutionary, cosmic and biological history? And how would one grasp the order and harmony of a nature crowned by the creation of human beings, if one considers that in the history that preceded them innumerable species appeared and disappeared, through mutual competition and sometimes painful conflicts? At the level of salvation history, might the very long ages which passed from the first appearance of the human species on earth facilitate the understanding of the relationship between objective and subjective redemption, considering above all that the great majority of human beings that have lived so far have never come into contact with the salvific message of Christ's Paschal event? These are just hints –also in this case the list may grow longer– that may suffice to give a sense of what we mean; not just for being potentially fruitful in themselves but for showing the need for serious and thorough interdisciplinary work, calling on capable scholars to use their competence to carry it out.

On the other side of the balance, of course, we could find problematic issues to solve. It becomes important to explain, for instance, the relationship between the "first" and the "new creation", finding suitable ways not to contradict our current knowledge of the material universe as well as of its past and future scenarios. An evaluation of the elements of continuity and discontinuity operating within that relationship, about which Biblical Revelation also informs us, should further be carried out on the basis of scientific insights, while consequent possible implications for eschatology, including intermediate eschatology, should be carefully examined. We should explicitly make clear that we are dealing with "implications", not necessarily with "problems"; it is nothing but a "common quest for understanding", from which the intelligibility of Revelation might take full advantage. With reference to the "physical" dimension undoubtedly contained in the relationship of continuity/discontinuity between the first and the new creation, theology should also define more precisely some elements linked to Original sin. Leaving out the hermeneutics underlying the Biblical account –being the exegetes' own task to explain it in accordance with the essential content of dogma– it seems clear that the historical entrance of sin into a world which had been in existence for a long time, is presented with its definite consequences not only for human nature, but also for the material world as a whole. Thus theology is asked to clarify whether the element of "discontinuity" introduced by such consequences may have any scientific observable. If so, a dialogue with the sciences would shed light on the way of viewing human death. For instance, it may suggest ways of distinguishing between a view of death understood as the completion of a biological cycle, which science tells us to occur in nature well before the appearance of *homo sapiens*, and death understood as the dramatic way in which a conscious rational creature feels the end of its physical existence while putting in doubt the goodness of its Creator. A dialogue with the sciences may further suggest that the disorder brought into nature by human sin would allow for interpretations stressing its anthropological implications (as a disorder introduced in the relationship between the sinner and nature) without necessarily insisting on its physical or natural implications (as a disorder within nature itself). Different ways of understanding what "physical pain" is, and what it means in God's plans, would also emerge. Finally, we could thereby derive some indications on the correct way of understanding the relationship between the historical and meta-historical dimensions of original sin itself.

The meaning and the logic of the history of salvation – being the history of God's freedom and of human freedom – certainly exceed what is expressed by the evolutionary histories of the cosmos and of life, and by any of its possible reconstructions provided by the sciences. And yet, the history of salvation is accomplished, that is it takes place and is intertwined in those histories studied by science. The realism of the mystery of the Incarnation, by which the Word-Logos, while taking upon himself human nature, also took up all its relations with creation, calls upon us to take into due consideration this intersection by fully exploring its consequences.

The importance of all this for theology has recently raised the need to develop a "theology of science" [Heller, 1996, 95-103] or even a "theology of nature" [Ganoczy, 1992]; [Pannnenberg, 1993]. Despite all the limitations of these theological approaches (sometimes called "theologies of", and thus not always met with favour because they are seen as potential sources of fragmentation), we believe that enough material is now available to start thinking along these lines. "Theology –as a contemporary author puts it– can only make a useful contribution inasmuch as it keeps in touch with the rest of the sciences. And in saying so we refer not just to the need for theology to make itself heard, but to the fact that it needs itself to listen to other sources of knowledge [...]. Theologians, just like any other scientists, need to be humble and to be so to an even greater extent; not only because they receive their knowledge from the word of God, entrusted to the Church, before which they have to maintain an attitude of devout attentiveness, but also because they recognise that theological science will not authorize them to do without other kinds of knowledge" [Illanes, 1982, 873-888, here 887].

Towards a Genuine Development of Christian Doctrine

Among the authors of the past who were fully aware of the value of the natural sciences for human knowledge, including theology, we should certainly mention Cardinal John Henry Newman (1801-1890). Even though he did not leave any particularly elaborate discussion of this matter, it is worth remembering that, in an epoch of hot debate and sometimes outright conflict between science and religious thought, he did not fail to offer meaningful reflections on the issue of evolution. His interest in the results of science was sincere and fully thought through: "We live in a wonderful age; the enlargement of the circle of secular knowledge just now is simply a bewilderment, and the more so, because it has the promise of continuing, and that with greater rapidity, and more signal results. Now these discoveries, certain or probable, have in matter of fact an indirect bearing upon religious opinions, and the question rises how are the respective claims of revelation and of natural sciences to be adjusted. Few minds in earnest can remain at ease without some sort of rational grounds for their religious belief; to reconcile theory and fact is almost an instinct of the mind. When then a flood of facts, ascertained or suspected, comes pouring in upon us, with a multitude of others in prospect, all believers in Revelation, be they Catholic or not, are roused to consider their bearing upon themselves" [Newman, 1864, 290].

We turn to Newman, again, to make a further step forward: what would it mean, then, to see the sciences of nature as a source of real development for Christian doctrine? The search for a proper methodology and for suitable guidelines to attain such a goal is a question that is still open. A possible answer could be achieved by considering the useful remarks Newman made in his work *The Development of Christian Doctrine* (1845). There he draws up a list of seven criteria that would guide the authentic historical development of a doctrine, as distinct from what determines its corruption. The context of his reflections is not provided by the dialogue of theology with the sciences, but by history at large as a yard stick for the progress of human enterprises. He wonders how Christian doctrine may be formulated in the future to incorporate new knowledge or new events occurring in history, without losing its own identity. It is ultimately a reflection upon the criteria of theological work, which, within its own autonomous domain and in line with the genuine interpretation of the Church's Magisterium, proposes new avenues to be taken and new ways of understanding what is still implicit and unexpressed in the body of Biblical Revelation. The criteria suggested were thus summarised by Newman himself: "I venture to set down seven Notes of various cogency, independence and applicability, to discriminate healthy developments of an idea from its state of corruption and decay, as follows: There is no corruption if it retains one and the same type, the same principles, the same organization; if its beginnings anticipate its subsequent phases, and its later phenomena protect and subserve its earlier; if it has a power of assimilation and revival, and a vigorous action from first to last" [Newman, 1845, 171]. Bearing in mind the context outlined in the previous sections about the possible intellectual contributions of the natural sciences to theology, we shall attempt to apply these criteria to our topic. I propose here the same headings reported by Newman (Cf. [Newman, 1845, 171-203]).

i) and ii) preservation of its type and continuity of its principles. These two first criteria indicate in a nutshell the "identity" of the subject that develops them. If theology wishes to take into account the results of the natural sciences, it must continue to be what it is, namely genuine theology, with its own method and its own customary sources. Theology does not have to turn into physics or into biology, nor theologians into laboratory researchers. Certain strains of contemporary theology, we guess, have attempted to link up with the sciences precisely in the opposite direction to that suggested by Newman, namely by choosing to adopt their methodology. The inclusion of authors such as Kuhn or Popper in many theological textbooks shows that quite clearly.

iii) Power of assimilation. It indicates the openness of theology on truth and history, resulting from its openness to the mystery of Being or to the mystery of God. Genuine theology has an ability to assimilate new true portions of knowledge whatever their origin, without corrupting its own identity or breaking into pieces. This Newmanian criterion points to the possibility of "reinterpreting reality", again and again, by embracing its demands for truth. During our recent history, and following watershed events in the history of science, as associated with the names of Copernicus, Christopher Columbus, Darwin, Freud, and others, some reinterpretations of certain contents of Revelation were made. A kind of reinterpretation, for instance, was that proposed by those theologians who tried to comprehend an evolutionary picture of creation derived first from Bergson, and later from Teilhard de Chardin. All these were authors who were very different from each other, and their philosophical positions have not always been consistent with the contents of the Christian Revelation. However, they played a significant role due to the scientific and cultural movements which originated from them and that entered into a crucial confrontation with theology.

iv) Logical sequence. The use of scientific results and of their implications must be such as to maintain the logical consistency of revealed truths, in other words not to contradict what has already been accepted as sound doctrine. This is ultimately no more than a direct application of the principle of the analogy of faith or *analogia fidei*. At first sight it would seem difficult to reconcile certain scientific results with the body of Christian doctrine, but once these have been examined in their true scientific value, and as they have been correctly interpreted and cautiously adopted, sooner or later they eventually shed new light on other contents of Revelation. The overall new vision resulting from the adoption of this fresh knowledge would, as a whole, turn out to be more consistent than the earlier one.

v) Anticipation of its future. If they are truly genuine, new developments should contain seminal material implicit in Biblical Revelation or in earlier theological traditions. For instance, the compatibility between creation and evolution could be discovered by conveniently interpreting some passages from the book of *Genesis* while referring back to Augustine or to Thomas Aquinas, or by finding seeds of it in St. Paul's Christology. The unlimited richness of the revealed divine Word would implicitly justify the application of this criterion.

vi) Conservative action upon its past. Scientific or cultural revolutions inevitably occur, but they are not entirely destructive, either for theology or for science. Any genuine development is always somewhat "conservative". As a result of the dialogue with the sciences, theology can adopt a new philosophical reference model as long as it preserves all the aspects of the dogma that were easily explained by the previous model. Something similar ultimately happens in the case of physics, where the so-called "classical" solutions are surpassed by those provided by quantum or relativity theories, but do not lose the content of truth they had in the previous theory. In fact, quantum and relativistic solutions often retrieve some "classical" truth in the form of particular cases within a more general interpretative framework. Consider the following examples: a different formulation of the mystery of the transformation of the Eucharistic bread and wine (transubstantiation) adjusted to contemporary scientific categories, could only be accepted if all previously accepted dogmatic aspects are preserved, and a better explanation of what the previous frame eventually failed to show is provided; likewise, if new forms of intelligent life were to be discovered in the universe, the fundamental elements of Christian Christological doctrine must be preserved, although included within an inevitably much wider horizon. Current doctrinal formulations are thus theology's "classical" solutions: to accept new developments means preserving what was provided for by previous solutions, thus acquiring a new and better knowledge.

vii) Doctrinal strengthening. According to Newman, any genuine doctrinal development produces a strengthening in its contents as well as in the Institution professing it. If theology ever used the results of the sciences incorrectly, it would sooner or later notice a weakening in its own ability to make sense of things, and in its own prophetic dimension –you will judge them by their fruits, as we are reminded by the Gospel (cf. Mt 12,33). Spiritual guidance and a fair amount of humility would then be needed to change the direction.

Despite our insistence on the contributions provided by science to theological reflection, we should not ignore the fact that mutual implications are still equally available from theological reflection to science.

As in the past, new insights for philosophical and scientific thought have been given to science by Biblical Revelation, through the intellectual mediation of theology. In many other essays these implications have been comprehensively highlighted. We also mean that the presence of the sciences in theological work should not merely respond to utilitarian or ancillary criteria: scientific research is a value in itself and it is meant to play, just like any other human activity and any sincere desire for knowledge, a precise role in the divine plan on creation, the plan of leading all things, by human work, to the Father, through Christ, in the Spirit. Our goal has been to point out that there is significant room for reflection in order to incorporate more decisively some achievements of scientific research into theological knowledge. We believe, in fact, that without such an assimilation –respectful of the past but open to future developments, cautious in discernment but also consistent with itself in the face of truth– theology could run the risk of engaging only in "defending" what a given age understood in the doctrinal content of the faith. As a result, it could impede the genuine development of the Church's doctrine, even to the extent of possibly weakening her mission of proclaiming the Gospel of salvation, in a credible and significant way, to all men and women of all ages.

Part II

Research

8

Experiments and Causality

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The relation between experiment in physics and causality are studied. Experiment requires a notion of causality which is not fully reducible to the efficient one, and involves considerations about top-down mode of causality. Agency approach to causality provides a suitable philosophical background for understanding experimental activity. Section 2 is dedicated to the understanding of what an experiment actually is. Section 3 concerns the issue of causality and those features of the agency approach to causality that are useful to understand the experimental activity. Section 4 applies the agency approach to causality to experiments. Section 5 handles with the top-down mode of causation suggesting several reasons why experiments very often involve top-down features.

Introduction

Experimentation is a fundamental aspect of the scientific enterprise; it does not only help us in testing our theories but it results also vital for the overall furthering of our scientific understanding of natural world. Philosophy of science extensively reflects upon the theoretical part of science since the birth of modern science; experimental part, on the contrary, is less frequently reflected upon. I think, on the contrary, experiments present a number of very interesting features from a philosophical point of view. Not only they are cognitive in character, but they are closely connected with many central philosophical themes.

In the present paper I shall study the relations between experiment and causality. We will see that causality provides interesting insights in understanding experimental activity, especially because top-down (or downward) causality – which is a theme recently imposed to the philosophical as well as scientific community – provides us with a fresh context to look at experiments. Experimentation, in turn, suggests – and, to some extent, requires – a restatement of the causality notions which lead to a non-strictly-efficient point of view. Section 2 is dedicated to the understanding of what an experiment actually is. Section 3 concerns the issue of causality and those features of the agency approach to causality that are useful to understand the experimental activity. Section 4 applies the agency approach to causality to experiments. Section 5 handles with the top-down mode of causation suggesting several reasons why experiments very often involve top-down features.

What an Experiment Is?

Any philosophical investigation needs, at its beginning, at least a preliminary definition of the object of the research. Of course, many such definitions have been proposed in the literature; however, as it frequently happens in philosophy, none of them is able to satisfy completely the experts of the field. That is essentially due to the nature of the subject-matter, which is really difficult to state in clear abstract and general terms capable of accounting for all the complex historical, as well as logical, features of experiment in science. In this section, I shall propose a definition of experiment in physics – which surely is the most experimental branch of scientific enterprise. In proposing it I do not want to state a comprehensive and absolute definition of what an experiment actually is; on the contrary my definition will only serve the purpose of both capturing some essential and general features of experiments and inquiring the relationships between experiment and causality. My claim, in fact, is that experimentation, in spite of quantum mechanical revolution and the furthering of complexity theory, still remains the kingdom of causality, even if one needs a more general than efficient causality notion (sect. 3.) and some limitations must be admitted as well (sect. 5.). Is it possible to define what an experiment is by starting directly from its uses in physics? In other words, is it possible to provide a functional definition of experiment? It seems to me one should answer in the negative for three reasons. First, the wide opinion that experiments are usually aimed at testing theories, if taken without further specifications and restrictions, is insufficient to grasp several essential features of experimental activity. Second, experiments actually play several different roles in physics, which are reducible neither to that of testing theories nor to a univocal characterization. Third, to refer only to the uses of experiments is to overlook a number of important features of the experimental activity as such, which are instead vital for properly understanding the fundamental role of experimentation. First. A widely maintained position is that experiments are aimed at testing theories. A sketched idea of what this is generally intended to mean is the following. Given a theory and a specification of initial values and boundary conditions, we are able to deduce, from the conjunction of them, certain empirical prediction of relevant physical magnitudes. An experiment, then, is nothing but the implementation of those initial values and boundary conditions, and the measurement of the final values of the relevant physical magnitudes. Therefore, if the predicted values and the measured ones coincide, we say that the theory is confirmed (or at least corroborated, according to Poppers advice), otherwise we are faced with a problem requiring further research. This schematic account surely teach us something important about the roles of experimentation in physics; but it fails to understand what is, in my opinion, one of the most fundamental feature of experimental activity. Roughly speaking, in order to test a theory, an experiment has to meet several important conditions other than that of reproducing a certain set of initial values and boundary conditions and that of allowing for the measurement of certain relevant physical magnitudes. An experiment, in fact, must perform, at least, the following two tasks:

> 1) It has to provide the researcher with strong reason to believe that its results are to be considered as an *actual* confirmation of the very theory from which the empirical consequences have been derived or calculated (of course, in conjunction with that initial values and boundary conditions implemented by and within the experimental set up).
> 2) It has to furnish guarantees about the input and output data concerning the values of the magnitudes at the beginning and at the end of each experimental run. This means that an experiment has to give security about both the accuracy and precision of the values involved and the absence of all the known possible sources of noise or perturbations.

Recalling that I am here considering that class of experiments aimed at testing a theory (or some of its empirical consequences), it will appear clearly that the guarantees required by 1) and 2) above cannot be entirely provided by the theory itself. My claim, in fact, is that for an experiment to test a theory, not all the possible initial values and boundary conditions – from which the theory is able to derive empirically testable consequences – are equally good. In other words, the way in which an experimenter can give rise to a reliable experiment, is to *select* a subset of all the initial and boundary conditions, among those admitted in the scope of the theory at hand, which are able to provide the guarantees required by 1) and 2). The theory which an experiment is aimed to test, in general, does not contain enough indications about how to do such a selection. Let us turn on the second reason why a satisfying definition of what an experiment is cannot be achieved by considering its aim only. The point is that in physics experiments are performed for different purposes, which are not reducible to that of testing theories. I think three fundamental uses of experiments can be individuated. The first one, of course, is that of testing theories. This is the most acknowledged in the literature, but it is not the most frequent in the history of science. The second one occurs when experimentalists are attempting at measuring the value of constants of nature (or other parameters of interest). It is clear that such experiments generally have many relevant consequences at the purely theoretical level and that in some interesting historical case they contribute to confirm or confute some theory as well. However, there are many cases in which accurate measurement of physical constant were performed without being aimed at testing any theory [Hacking, 1997, 234-245]; [Kuhn, 1977, 220]. The third fundamental use of experiments is the *exploratory* use [Steinle, 1997, S65-S74]. The main characteristic of this class of experiments is that they do not constitute attempts at finding some empirical effect either predicted by a theory or following a theoretical hypothesis; rather, their aim is "simply" to look at how things go. It has been recently emphasized that several important experimental programmes have been carried out with the only ends of "*collecting and analysing a gigantic mass of data, in order to find characteristic patterns*", without having any definite theory about the data handled with [Wolters, 2003, 297].

Before turning on the third reason why the experimentation cannot be appropriately characterized by its aims only, it is worth noting that the distinction between those three class of experiments involves also the issue of the theory-experiment relationship. In fact, a use of experiments exists whose first end is that of testing theories: I label those as "theory-driven experiments". There are two other classes of experiments – the one clustering those performed to measure constants of nature (or other interesting values), the other including exploratory experiments – which are not designed to test the empirical consequences of any definite theory or hypothesis: I call both these kind of experiments "theory-laden experiments". This paper is not concerned with this question, but it is important to stress that also those experiments which are not aimed at testing theories do require theoretical commitments to be designed. Actually, one of the consequences of this whole paper is that an experiment, to be meaningful, needs many theoretical assumptions and hypotheses; however this does not mean at all that any experiment is carried out to test a theory.

Can we achieve some general characterization of experimentation from the previous classification? There is, indeed, a feature which is common to all the three classes of experiments and independent of the specific aim characterizing each class: Experiments are carried out to extract *reliable* knowledge of nature. Thus, the previous classification would only show that such a knowledge can be used for at least three different purposes. The emphasis on the reliability is a key point, for I maintain that exactly this is the ground reason why humans do design and perform experiments. However, reliability is not a specific feature of experimentation. It rather concerns the whole human knowledge, from science to practical and daily intelligent behaviour, from sociology and economics to technology. The question, therefore, is about the *specific way* by which experimentation achieves – or tries to achieve – reliable knowledge of nature. This is the third reason why experimentation cannot be understood by considering its aims only. What is required, indeed, is an account of the specific way with which experimentation contribute to the human scientific knowledge of the natural world. It may seem, therefore, that what is needed to this end is a list of definite strategies used in experimentation. Several attempts have been made in this direction (See, for example: [Franklin, 1994, 104], [Mach, 1905, 148-157]), and much valuable information provided about the *modus operandi* of an experimenter at work. Unfortunately, listing the actual experimental strategies may be an endless task, for each experiment is faced with particular difficulties, requires peculiar procedures, handles definite portions of physical reality, uses different instruments, pursues different ends (as we have seen), is carried out by a certain team and, finally, is linked to various theoretical elements. In fact, the "listing-approach" has been recently criticized by G. Hon, who affirms that any list of experimental strategies finally results in "*an open*, ad hoc *list*" [Hon, 2003, 264-269]. In his "An Attempt at a Philosophy of Experiment" he outlines an approach to experimentation from the perspective of the possible sources of experimental error. He claims that it is possible to understand the experimental activity by taking into account the classes of errors which an experiment must avoid, and "*by examining* *and ordering possible sources of error in experiment*" [Hon, 2003, 269]. He proposes such a classification, which is inspired to the Bacon's theory of the four idols [Hon, 2003, 269-281]. I will not present Hon's positions in detail; however it is worth noting that this approach clearly indicates that a central point is that experiments are designed exactly to lower the possibility of misunderstanding what the behaviour of physical systems is telling us about themselves and their physical properties. This is, of course, a way – and perhaps the most interesting one – to understand the meaning of the *reliability* demanded for experimental knowledge of nature. The question of reliability seems, therefore, central to our purpose. There are many different features of reliability; it may be intended as numerical accuracy, instrumental efficiency, repeatability and even interpretational clarity. I think however that the hard-core of such a notion can be individuated in the following way: An experiment is reliable when it is clear what any component of the obtained outcome is due to. How the expression "component of the outcome" must be understood requires some explication. The point is that a physical process – artificial as well as natural – involves, in general, a multitude of physically active factors and the outcome – which is produced by more or less complex interactions between those factors – can be regarded as compounded by many elements or features: They are the "components of the outcome". Of course, the establishment of such elements is not absolute; rather, it is relative to what is really interesting in the experiment performed, and then, to the theoretical commitments, the level of graining, the aims, the means, etc. However relative, such decomposition – such analysis – of the outcome is commonly considered in physics. It may suffice thinking at the exercises students usually solve. Technological and engineering problems too – which often are problems of optimization – usually require a decomposition of the whole problem into sub-problems which are more tractable and where the links between input and output factors appear easily. I am aware that it is not simple to establish such "elementary" links between an input factor and a component of the output; however, in my opinion, this is exactly the fundamental source of experimental error. An experiment carries to erroneous conclusions when it induces the researcher to maintain wrong dependence-relationships between input and output factors. This hold true for any of the three kind of experiment we distinguished above. The experimenters skill, in fact, always consists in giving raise to experimental set-ups and procedures capable of providing a high degree of clarity about those "elementary" links. All this will become clearer in section 4. below. The input factors just mentioned are usually labelled as initial values and boundary conditions. The best way to try to establish the right links of the input factors with the components of the outcome is that of producing and manipulating in a suitable and controlled way those factors and of eventually noting the resulting changes in the outcome. This suggests a general definition of what an experiment is.

Experiments are accurately designed *manipulations* of the physical world characterized by the *controlled* production and variation of initial values and boundary conditions and the eventual recording of the outputs. The general aim of experiments is that of providing a *reliable* knowledge about the elementary links between input factors and the components of the output.

The latter is a general definition whose precise meaning needs further elaboration to show its usefulness and suitability. This work will be done in what follows. However, I want to stress here that the definition suggests a way for distinguishing between experiment and observation. We have an observation, and not an experiment, when, either for principle or practical reasons, it is not possible to (adequately) manipulate the input factors. Clear examples of observations are easily found in astronomy, for it is impossible to us to intervene on planets, stars or galaxies. This distinction does not imply that observations are merely passive recording of data; they often require great skills, comparable with those required for experiments. A good example is provided by the Penzias and Wilson's discovery of the 3^oK uniform background radiation (see [Hacking, 1997, 159-161]). The radio-astronomers were seeking for sources of radio energy in space, and they noted that a small amount of energy comes from empty space where no source appeared. The first value they detected was about 4^oK; they were astonished and tried to eliminate all possible sources in the neighbourhoods of their radio telescope and repeatedly controlled their instrumentation. A 3^oK energy still remained. According to my definition, Penzias and Wilson were not performing an experiment, for they could interfere neither with the source of such radio energy nor with *its* boundary environment. On the contrary, they thought that the radiation cannot be due but to some unknown source in the neighbourhoods of their laboratory. When all reasonable such possible sources were eliminated they were inclined to admit that the universe has a uniform temperature of 3^oK, although there was no suitable explanation for it. I think that they believed in the existence of such background radiation exactly because, according to my definition, they were aware of being doing an observation, and not an experiment. That is to say, their efforts were exactly aimed at eliminating all the possible factors potentially able to interfere with their radio telescope; when they thought the job was done, then, such a radiation had to be considered genuinely coming from the empty space.

To put all this in more general terms, I think that when we are sure that, according to my definition, we are actually performing an observation – and not an experiment – we are entitled to believe that what is observed exists in reality independently of our intervention and it is objective[1]. In such case, however, the problem is that of establishing what the observed effect or phenomena is due to – this problem is instead more easily tractable in experiments, as we will see. Differently, when manipulations are carried out on initial values and boundary conditions (the input factors) – *i.e.*, when an experiment is run – interventions on the object-system actually take place. These interventions may give raise to artifacts [Rasmussen, 1993][2], which are facts, effects or phenomena produced by our own intervention rather than due to the spontaneous behaviour of the object-system. If the artifacts are recognised and their source known, then, they may provide useful information about the object-system, otherwise they usually bring to erroneous conclusions. It is true that artifacts can occur even when we are observing (Penzias and Wilson initially thought that the 4^0K radiation was indeed an artifact); in such cases, however, they are due to some perturbation acting *on the information* (*i.e.*, physical signals) *coming from* the observed source and effecting our receiving instrument[3] but not to some intervention *on the source itself.*

Causality

Causality is as central as problematic a notion in philosophy of science. During the history of philosophy it undergoes several shifts in meaning. Since my purpose is that of maintaining that experimentation is better understood with the help of causality, it is necessary to precisely state the notion of causality I am referring to. The first accomplished and famous theory of causality is certainly that of Aristotle who, as it is well

[1] I thank Prof. Marc Leclerc sj for suggesting me this interesting feature of observation.

[2] This paper is concerned with electron-microscope observations of Bacteria division. It can be argued that we make observations, and not experiments, with microscopes. However, (1) that we simply see through a microscope is a discussed issue. See [Hacking, 1981]; [Hacking, 1997, 186-209]; (2) the artifacts studied in the Rasmussen's paper are due to the specimen preparation procedures, that is, to interventions on the object-systems.

[3] I thank Prof. Gennaro Auletta for suggesting me that when we observe we do interact with the effects coming from the source.

known, individuated four kinds of cause. Such a conceptual richness was lost with the advent of modern science, whose paradigm is Newtonian mechanics. The only kind of causality among Aristotle's maintained to agree with such a paradigm was the efficient one. The basic reason to reject all forms of causality but the efficient one depends on the mechanistic nature of classical physics [Auletta, 2004a] and particularly on the law determinism emphasized by modern science. It would be interesting to take into account the way in which this shift of the causality notion took place and its far-reaching consequences, but this is completely out of the scope of this paper. Rather, the notion of efficient causality itself is not as unproblematic as it may appear; the following analysis shows that there are two different fundamental approaches to efficient causality in contemporary philosophy of science. The first one can be said the physicalistic approach to causality, "*in which an attempt is made to provide an account to causation in terms of physical descriptions of events or state of affair, i.e., descriptions according to our best physical theories*"[Dieks, 1986, 85]. The principal theories of physicalistic causality are the so called transference models. Many slightly different such models have been proposed by several authors [Fair, 1979]; [Aronson, 1971], [Salmon, 1980], [Salmon, 1984], [Salmon, 1994]; the best of them, in my opinion, is the one elaborated by Philipp Dowe. The central notions, here, are: Causal interaction: "*A causal interaction is an intersection of world lines which involves an exchange of a conserved quantity*" [Dowe, 1992, 210]; Causal process: "*A causal process is a world line of an object which possesses a conserved quantity*" [Dowe, 1995, 323].

Therefore, causation occurs whenever two (or more) causal processes interact and a conserved quantity exchange takes place. The direction of causation is, then, identified by the direction of the flow of such quantity. The most elementary domain where conserved quantity theories of causation prove applicable – which is, in fact, the most frequently referred to by their proponents – is particles physics. It should appear clearly that the approach is strongly based upon the fundamental physical laws ruling particle interactions. In a very general way, an account of particle interactions is obtained by conservation laws plus properties of the particles involved plus, of course, initial and boundary conditions. An important point to be stressed is that such an approach relies strongly on the account of the *fundamental physical mechanisms* acting in particle interactions; physicalistic causality, therefore, presupposes the theoretical models concerning such interactions. Many discussions developed about pro and contra of this approach to causality, especially in the 1990s. We do not need to consider them extensively, for we are concerned with experiments and, rather, we should ask: Can this approach provide some insights for understanding the experimental activity as sketched in the previous section? There are reasons to answer in the negative. The transference approach to causality should be regarded as an attempt at explicating how causation is to be understood on the ground of the laws provided by our best physical theories. These laws are *not causal* in character, rather, as Bertrand Russell pointed out already in 1913, they are functional laws expressed by differential equations [Russell, 1994, 173-186]. Russell argues that causality do not play any role in mature physical theories, like, he says, gravitational astronomy. He also argues that causal laws play an important role in the infancy of some scientific branch but, once it furthers, causal laws are replaced and concentrated in non-causal functional ones. I think that is often true, and a clear example is the origin of thermodynamics. Sadi Carnot developed his theory at a time when steam-engines were already usual in mines, as he himself recognises [Carnot, 1872, 393-400]. It is also true that the well-known ideal gas law:

$$\mathrm{PV} = \mathrm{nRT}$$

is a mathematical relation stating a functional dependence among macroscopic variables, but it also "*yields different causal laws when applied to different situation*" [Gillies, 2005, 830]. For example it says that if we rise the temperature of a certain fixed volume of gas, then pressure grows up proportionally. It is true that at a purely theoretical level we can well neglect those causal laws and refer only to the functional ones, but if "*we apply the [latter] law to a particular concrete situation were a gas is being manipulated in some way, causal notions do reappear*" [Gillies, 2005, 829]. All this suggests that, when dealing with experimentation, causal laws are to be seriously taken into account, although they cannot be meant as purely functional ones. Transference models of causality – and in general the physicalistic approach – are neither necessary nor sufficient to give an account of the experimental activity in physics. They are not sufficient because having a theory, or a theoretical model, of a certain physical situation or domain does not imply the actual possibility of testing it experimentally. History of science shows a certain number of cases in which:

- there was a well developed theory – or a theoretical model – of the fundamental physical mechanisms pertaining a certain physical domain, at time t_1;
- that theory proved to be satisfying (*i.e.*, empirically adequate) at time $t_2 > t_1$;

- but it did not undergo an experimental control till t_2 for non-theoretical reasons; either technological limits or the simple fact that a suitable experimental procedure had not been developed until t_2, are, indeed, possible impediments.

The knowledge of the fundamental physical mechanisms is not even necessary to design experiments on a certain physical domain. As we have seen in the previous section, there are experiments aimed at discovering how things go, without having already a theory. Moreover, the possibility of successfully interacting with nature does not presuppose at all a theory about those fundamental physical mechanisms required by the physicalistic approach. Steam engines developed before thermodynamics, and this latter, in turn, came before statistical mechanics – which relates the macroscopic thermo-dynamical magnitudes with the microscopic variables, thus providing a theory of the fundamental mechanism acting in thermo-dynamical systems.

We have, therefore, to turn on the second general way of approaching causality, that in terms of manipulation, intervention and agency[4]. The essential intuition at the basis of this approach is that causal notions are strictly linked to the human capability of acting in nature.

> *Thus, the statement about the cause of something is very closely connected with a recipe for producing it or for preventing it. [...] We could come rather closer to the meaning of "A causes B" if we said: "Events of the B sort can be produced by means of producing events of the sort A"* . [Gasking, 1995, 483].

'Recipe' is also labelled by Gasking as a 'general manipulative technique'. To cause B we have to produce A, and to make A happen we must be in possession of a suitable technique (a procedure, a rule for action). The connection of this approach to causality with the experimental activity is straightforward, and it is explicitly admitted too:

> *It is* established *that there is a causal connection between p and q when we have satisfied ourselves that, by manipulating the one factor we can achieve or bring it about that the other is, or is not, there. We usually satisfy ourselves as to this by making experiments.* [von Wright, 1971, 72].

[4]Sometimes, this terms denote slightly different theories elaborated by different authors or schools; however in this paper they will play an interchangeable role.

The next section is dedicated to the application to experiments of this approach to causality. Now we have to deepen those intuitions to achieve a more accomplished theory of manipulation causality. First of all, as already mentioned, there is an important difference between manipulation and transference causality (treated above); whereas the latter is concerned with continuum processes and fundamental interactions between elementary physical systems, the former takes into account the causal links between discrete events and it is not interested in the fundamental physical mechanisms underlying what happens when a factor is manipulated in view of producing, avoiding or modifying another one. Second, manipulation causality cannot be considered as an attempt at *reducing* causal concepts to other more fundamental notions; it is in fact widely recognised that the very notions of manipulation and intervention are causal in character. It is, rather, aimed at providing a theory of *causal discovery*; that is, a theory about the ways in which humans extract reliable causal knowledge from nature. To this extent a great modern philosopher has much to tell us. In his *System of Logic*, as it is very well known, J. S. Mill states his four methods for experimental inquiry. The first two – which are surely the most fundamental ones – are the Method of Agreement and the Method of Difference [Mill, 3 74, Book III, Ch. VIII, 1 e 2]. He says:

> *Of these two methods, that of Difference is more particularly a method of artificial experiment; while that of Agreement is more especially the resource employed where experimentation is impossible.* [Mill, 3 74, Book III, Ch. VIII, 3]

Mill himself explicitly admits that the method of difference is the most powerful one and that it is by this alone that we can achieve a knowledge about the actual causal links among relevant factors, whereas by the method of agreement we can solely establish the presence of some uniformity, without any causal import [Mill, 3 74, Book III, Ch. VIII, end of 3]. In fact, he says that even if we have established – thanks to the method of agreement – that a determined factor A invariably precedes another factor *a* that does not suffice to conclude a causal link between A and *a* holds:

> *[...] to determine whether this invariable antecedent is a cause, or this invariable consequent an effect, we must be able, in addition, to produce the one by means of the other; or, at least, to obtain that which alone constitutes our assurance of having produced anything, namely, an instance in which the effect,* a *, has come into existence, with no other*

> *change in the pre-existing circumstances than the addition of A. And this, if we can do it, is an application of the Method of Difference, not of the Method of Agreement.* [*Ibidem*].

This quotation can be in all respects considered as the ancestor of the contemporary agency theories of causation, as it can be seen from the requirement of producing *a* through A to establish the casual link. However, such casual conclusion demands the fulfilment of a strict condition, namely, that the only change in the circumstance must be the implementation of A. Exactly this is the reason why Mill maintains that one needs using the method of difference and, therefore, performing an experiment is needed. Once again, Mill states the point with admirable clearness:

> *It is inherent to the peculiar character of the Method of Difference, that the nature of the combinations which it requires is much more strictly defined than in the Method of Agreement. The two instances which are to be compared to one another must be exactly similar, in all circumstances except the one which we are attempting to investigate; [...] it is very seldom that nature affords two instances, of which we can be assured that they stand in this precise relation to one another. In the spontaneous operations of nature there is generally such complication and such obscurity, they are mostly either on so overwhelming large or on so inaccessible minute scale, we are so ignorant of a great part of the facts which really take place, and even those of which we are not ignorant are so multitudinous, and therefore so seldom exactly alike in any two cases, that a spontaneous experiment, of the kind required by the Method of Difference is commonly not to be found. When, on the contrary, we obtain a phenomenon by an artificial experiment, a pair of instances such as the method require is obtained almost as a matter of course [...].* [Mill, 3 74, Book III, Ch. VIII, end of 3].

Here it is clearly suggested that to extract reliable causal knowledge the *whole* experimental situation must be artificially implemented. This is due to the necessity of having a control on the great part (if not the totality) of the (relevant) factors involved in the investigated situation. It is, therefore, vital to rest assured about which factors are *actually* at work, and to what extent, and about the fact that no *hidden* factor is allowed to affect the situation.

I think it is possible and useful interpreting the latter quotation from Mills book according to a recent intuition by P. Menzies and H. Price, who maintained that being able to produce a certain factor, event or phenomenon as a consequence of an agent free action is "*creating for it an independent causal history*" [Menzies and Price, 1993, 191] [5]. The key point here is exactly that the capability of giving rise to some determined occurrence by our own actions provides with strong indications about which factors are actually at work. This is, in my opinion, the fundamental reason to distinguish between cases in which an occurrence stems from a spontaneous and uncontrolled circumstance and cases where the same occurrence is produced in an artificial and controlled way. It is now worth stressing another important point from agency theories of causation. So far, I have essentially referred to *productive* actions, that is, actions performed to put in existence some factor, event or effect. However, for reasons which will become clearer in the next section, it is important to recognise a central role to *avoidance* actions too [Gillies, 2005, 829]. The most simple example of such kind of action is when, knowing that A causes B, we prevent A from happening to avoid B occurs. Of course, that is not a fail-safe method unless we are sure to avoid any possible cause of B. There exists another type of avoidance action, which "*is based on pre-empting A from producing its normal effect B*" (*ibidem*). Generally, A causes B *ceteris paribus*; we can avoid that A causes B, even though A still occurs, by altering some of those *ceteris paribus* conditions required for A to produce B. It is apparent that such avoidance strategies are widely used in experimental activity.

In concluding this section, one must note that the approach to causality via agency and intervention indeed enlarges the scope of the causality notion, at least with respect to the identification, operated in modern philosophy, of causation, law and determinism. That is, agency theory of causality recognizes a causal role to a number of factor kinds which are not strictly efficient according to the viewpoint of modern science and philosophy. There are two moves determining such a conceptual enlargement. The first is the one just stressed: the consideration of avoidance actions. Such actions cannot be considered as being responsible for the production of some effect: They prevent it from occurring. It is certainly true that an action can be an avoidance one relatively to the particular experimental context we are handling with and nonetheless be of an ef-

[5] The authors are concerned with probabilistic causality; I think, however, their idea is perfectly applicable to non-probabilistic causality. Probabilistic causality is, in fact, a generalization of the latter.

ficient kind *per se*; however what counts here is whether such action is efficient with respect to the investigated object-system. Consider, for example, an avoidance action performed to shield the object-system from some possible undesired interactive factor; the action may be – and in general is – plainly efficient for the interactive factor, but it does not have at all an efficient influence on the object system. The second point is the overlooking of the fundamental physical mechanisms possibly underlying the causal links as individuated by agency causality. As we have seen, agency approach to causality distinguishes itself from the physicalistic approach exactly because, differently from the latter, it does not explicitly consider the physical laws – as expressed by functions and differential equations – describing – or attempting to describe – the physical mechanisms involved in the situation handled with. Thus, many antecedents can be considered as causes of some consequent – which, then, becomes their effect – even if the laws stating the physical mechanism connecting the two parts is not (already) known. Some proponents of the agency approach to causality, in fact, conceive the cause-effect relation in terms of the means-end one [Price, 1992, 514-515], and they leave the physical mechanisms unspecified, as they were in a "black-box' between input and output. Of course, such causal knowledge is less informative than that achievable via physicalistic causality, but it is undeniable that such kind of inferences often take place in physics, especially when a new branch is rising. The next section shows how experiments are to be understood in terms of the interventionist view of causation.

Experiments as the Kingdom of Causality

From the previous two sections it should appear clearly that interventionist account of causation provides an adequate understanding of what characterizes the experimental activity. Essentially, experiments have to be regarded as controlled manipulations of physical world. We have seen that a key feature of experiment is that of providing *reliable* knowledge about the elementary causal links between input and output factors. With the help of the Agency Theories of Causation the importance of avoidance as well as productive actions had been stressed and the reasons had been stated why well designed interventions are required to reliably establish causal connections. The exigency of being sure about which factors are *actually* at work, and to what extent, and about the fact that no *hidden* factor is affecting the situation at hand resulted from our examination of agency approach to causality. Of course, the best way to have these assurances is:

> i) to produce and implement artificially and in a controlled way *all* the factors required for the experiment;
> ii) to keep the whole experimental set up (or at least the object-system) isolated from both any possible source of perturbation and undesired interactive factors;
> iii) when that is impossible, to add compensative factors to neutralize the consequences of those undesired factors which are impossible to eliminate.
> iv) to be sure that those compensative factors do not actually affect other elements than those for which they are introduced – this often require what in the literature is frequently termed as background causal knowledge.

It should be straightforward admitting that, to deploy this general procedure, productive and avoidance actions – as meant by the agency approach to causality – are needed. Both the success and the reliability of an experiment, as well as its *epistemological meaning*, depend on such a general procedure. Therefore experimentation is to be regarded as the kingdom of causality, being causality understood in terms of agency, intervention and manipulation.

Productive and avoidance actions are the core of the experimental activity. However, any real experiment is characterized by its own overall structure; the entire set-up is decisive to accomplish the reliability required by the experimental inquiry of nature. Given that each input factor can affect many output elements and, conversely, each determinate output element often depends on the interaction of many input factors, what becomes relevant are not the single connections between input and output but the whole network of relationships among all the elements and factors involved. From the point of view of its *epistemological* (cognitive) *meaning*, an experiment cannot be regarded as the mere sum of the elementary causal links that are acting – or that we think they are acting; on the contrary, what really counts is the entire set-up thought of as a whole.

Now, it is important to stress that the factors which are relevant in that network are not only those of the efficient one. There are many different features of the experimental set-up which are of great importance for the reliability of the experiment itself. The efficient factors can be identified as the responsible of productive actions; they are those factors which posses the power of producing positively a certain effect in the experimental situation. Those are the factors able to do work[Auletta,]. The point here, however, is that in a determinate experiment the set-up is defined even by non-efficient elements, *i.e.*, the geometrical disposition of the various parts, the operations time sequence, as well as those devices serving the task of keeping the object-system isolated from perturbations *without* acting on the system itself, etc. Sometimes, the non-efficient factors are decisive for the *epistemological meaning* of the experiment itself. For an experiment to be actually able of providing strong reasons to believe that things go in a certain way and not otherwise, that some physical (theoretical) entities behave according to a certain law and posses determinate properties and that the output depends on a definite set of input factors (and not on different hidden ones), in many cases, the non efficient factors are of the greatest importance because they often play a decisive role in deploying the general procedure sketched above in this section.

Therefore, there are two fundamental reasons to maintain that experiments constitute the kingdom of causality as meant by agency approach. The first one, already treated in the previous section, concerns what is actually done in attempting to achieve the *reliability* about the elementary causal links holding in a certain physical situation or domain. The second one has to do with the *epistemological meaning* an experiment assumes, which generally depends on its capability to give rise to either a univocal picture about what is happening, or a small number of well defined such pictures[6]. This requirement is fulfilled by imposing suitable *constraints* on the behaviour of the object system. The constraints may be just avoidance actions, but in the most general case they depend on the overall structure of the experimental set-up, that is, on the ensemble of the physical and geometrical relations among the various devices involved, both those playing an efficient role on the object system and those of a non-efficient influence. This is an important point; in fact, when an experiment do not provide with a univocal picture of the physical situation, and then, when some different possible *interpretations* exist, a new experiment is usually designed aimed at deciding among these possibilities. As a matter of fact, such new experiments are obtained by changing some details in either the set-up structure or the initial values and boundary conditions, but, however slight this modification is, if the new experiment allows deciding among

[6]Surely, such pictures depends also on the theoretical elements the experiment is committed to, even if, as suggested in section 2, this does not implies that experiments are always aimed at testing a definite theory.

different possibilities which was not distinguishable by the previous one, then that slight variation must result in a meaningful change in the overall structure of the experiment. The reference to the overall structure of an experiment and to constraints as relevant for both its reliability and its epistemological meaning, hints at the possibility of taking in account the notion of "*downward causation*"; the next section is, in fact, dedicated to such an issue.

Top-down Mode of Causality

Here an attempt is made to intend the experimental activity in physics as a realm where top-down mode of causality is applicable, and to what extent. Before starting with the arguments, a brief terminological note is needed. The term "downward causation" appeared for the first time explicitly in the 1974 Campbell's paper[7]. Much research has been made about the issue and several different notions of downward causation have been stated[8]. Sometimes the same general concept is referred to as 'top-down action'. I prefer the locution 'top-down mode of causality' (or sometimes: 'top-down causality') to stress the fact that downward causation, as I conceive it, must *not* be meant as an *efficient action* of the higher level (the whole) on the elements of the lower one (the parts); that is grounded upon the idea that efficient causality may only exist between entities at the same level of reality [Auletta,] [Emmeche, 2000, 17 and 22]. Rather, top-down causality should be intended as *affecting* a lower level element in a non efficient way. Apart from this caution, the locution wants to cover the same concept as 'top-down action' and 'downward causation'.

Usually, the notion of top-down causality is concerned when one is dealing with complex and biological systems, and it might appear unusual that such a notion is considered in a reflection about physics experiments, especially because I am referring to experiments in general – and not only to complexity theory or quantum mechanics. However, I think that a weak notion of top-down causality results very useful in understanding what the experimental activity essentially consists in. Before stating such a weak notion, some words about top-down causality in general may be useful. We have this mode of causality when the higher-level structure "*provides the context in which the lower level causality*

[7]There is downward causation when "*all processes at a lower level of a hierarchy are restrained by and act in conformity to the laws of the higher level*" [Campbell, 1974].

[8]See, for example, [Emmeche, 2000]

functions" [Ellis, 2006b, 3.2], and its influences "*modify the properties of the constitutive elements at the lower levels*" [Ellis, 2006b, 3.3]. Top-down causality should be seen as a kind of formal causes "*understood in terms of constraints of a higher level of organization on lower level*" [Auletta,].[9] It is then clear that the central notions in top-down causality are those of organization and structure: An entity, or a certain part, of a higher level constitutes a whole which is not reducible to the sum of the lower level elements; such an irreducibility is due to the relevance of the structure in which those elements are set. This structure plays a constraining role: It, in fact, selects a sub-set of the possible efficient-interaction-abstract-set allowed by the lower level constitutive elements, and does this by imposing definite relations among the latter elements. As we have seen (sect. 3), these relations are not only of the efficient type. Some indication on how the notion of top-down causality can be applied to experiment can be already found. However, let us turn on the definition of weak top-down causality[10]. This notion stems from the following assumptions:

> 1) *A higher level entity [...] consists of entities belonging to the lower level [...]. These lower level entities are constituents of the higher level and are organized in a certain way that yields the higher level entity [...]. This does not mean that the higher level can be reduced to the lower (in which case no levels would be relevant), but that the higher level does not add any substance to the entities of the lower level.* [Emmeche, 2000, 16]
> 2) *The structure, organisation or form of an entity is an objectively existent and irreducible feature of it. The specific form characterizing a higher level entity (organizing its lower level constituents) cannot be reduced to lower level forms or substances.* [*ibidem*].

Accordingly, the higher level is constituted by a certain organizing structure of lower level elements. That such a structure, in many cases, cannot be reduced to the simple sum of the constituents can be seen from the fact that a higher level entity – even if thought of as it follows from assumption 1) – constrains its constitutive elements in specific ways and acquires new properties. As an example, consider a water molecule: it forces the component atoms to certain specific reciprocal relations and,

[9] See also [Emmeche, 2000, 25-26, 31]

[10] I take this definition from [Emmeche, 2000]. The authors refer to weak *downward causation*, but, according to the terminological note above, I use their definition for defining weak *top-down causality*.

in turn, assumes properties that are not reducible to that of oxygen and hydrogen taken separately. Another "*dramatic example is the properties of neutrons*": very stable when bounded into a nucleus and unstable when unbound [Ellis, 2006b, 3.3]. This weak notion of top-down causality, it seems to me, can be applied to the description of any experiment – as thought of in the previous sections. The outcome of an experiment, in fact, is the consequence of both the efficient factors involved and the overall structure of the set-up which provides the context (the environment) where the efficient factors act. It is the set-up that "decides" which efficient factor is allowed to act, upon what it can act, when it acts, etc. Two different set-ups, made of the same constituent elements and the same efficient factors organized in various ways, usually give rise to various outcomes; such a difference is due to the different *networks* of relations among the elements and factors imposed by the set-up. To this extent, the set-up as a whole indeed constrains the behaviour of the efficient factors and the effect they produce. To put all this in another way, the set of the involved elements and factors allows (abstractly) a wide range of efficient behaviours, whereas the organization provided by the set-up selects the one which will actually occur.

There is another important aspect, strictly connected with the previous one, which leads to recognise a "top-down feature" in experiments: they show a certain kind of *modularity* [Ellis, 2006a] and [Ellis, 2006b]. Very often, complicated experiments count several steps which have to be performed in a precise space-temporal order. Each of these steps is deployed by a specific device; each device is designed (or simply able) to do a certain set of operations. A whole experiment can be decomposed in sub-unities with a certain autonomy. However, the whole experiment depends crucially on the network in which the devices are set. Again, different settings of the same devices give rise to different overall situations. There are three other points hinting at the relevance of top-down considerations for experiments.

A) *Artificial isolation of physical systems.* Much physics is reductionist in character whereas top-down causality has strong anti-reductionistic claims. The very notion of isolated system is central for the success of the reductionistic approach in that it allows physicists to understand the fundamental efficient causal elements of the physical reality [Ellis, 2006b, 1]. However, truly isolated systems do not exist at all; they are abstractions. Experiments can be done upon systems considered as isolated, even if they are not in fact isolated, because it is possible to put a physical system within a context where all and only the disturbances relevant for a particular inquiry are either neutralized or reduced to a negligible intensity. Therefore, an isolated system is not actually shielded from the environment, but it is merely put in a suitable context; a context which is constructed or implemented by the experimenter exactly in the way we considered throughout sections 2-4.

B) *Time arrow* [Ellis, 2006b, 3.4.4]. It is well know that the direction of time cannot be deduced from the fundamental physical laws, for they make use of second time derivatives. This means that if we have a system evolving from the state A to the state B, the fundamental physical laws allow the inverse path (from B to A) as well. However the initial and boundary conditions associated with A are completely different from that for B [Auletta,]. Given that such boundary conditions depend on the global context in a top-down way, it is once again the context that determines the time arrow and then the temporal evolution followed locally.

C) "*The creation of phenomena*" [Hacking, 1997, 220-232][11]. With this expression I. Hacking refers to Hall effect (when a current passes in a conductor thin sheet, in a magnetic field, a potential develops at right angles to the field and to the current). He maintains that such an effect "*does not exist outside of certain kinds of apparatus*' [Hacking, 1997, 226], and that for this effect to exist a precise arrangement must occur in nature. Therefore the effect was not properly discovered by Hall, rather it was created. However emphatic, Hacking's point stress that, in several cases, a certain peculiar behaviour of an otherwise well known entity, is essentially dependent on the context. Of course, such a peculiar behaviour does not contradict to the fundamental physical laws but exhibits an emergent behaviour displaying new properties. This point is also connected with the previous one; in fact, the author says that the Hall effect "*did not exist until, with great ingenuity, he had discovered how to* isolate*, purify it, create it in the laboratory*" [*ibidem.* Emphasis added].

A final point has to be recalled. The last three points (A to C) try to show some reason to admit top-down causality regarding experiment without explicitly considering its epistemological role. However, as we have already stressed, an experiment is always *designed* in order to ex-

[11]The quotation is the title of the 13th chapter of the book.

tract reliable knowledge from nature, so that it is cognitive in character. Exactly this was the point which led us to considering top-down mode of causality. To this extent, therefore, an experiment must be considered as something strongly influenced by the human rational activity: an experiment is designed taking explicitly into account a number of theoretical commitments (see sect. 2 above). Such commitments play an important role in designing experiments. In the previous section, in fact, it had been seen that to achieve assurances about the reliability of experimental conclusions a general strategy must be deployed. This strategy results in giving rise to experimental overall set-ups such that they are able – at least in principle – to realize in the material world those networks of theoretical relations contained (and explicitly stated) in the experiment plans[12]. The precise, well-designed overall structure of experiments plays a so decisive role (as seen in sect. 4) exactly because (and to the extent to which) it is in conformity with the theoretical and conceptual network underlying its plan. Moreover, experiments always use manufactured objects and devices (this point follows directly from both the distinction between experiment and observation (sect.2) and the relevance of agency causality treated in sect. 3). That class of things displays characteristics which often make them essentially different from natural objects. Many such objects have feedback control loops – which are present only in living complex systems and in manufactured objects obeying a rational plan – and it is hardly deniable the they often play an important role in experiments, for they are vital in all those circumstances where some parameters must remain constant during the experimental run (i.e., a thermostat). A valuable point – which I cannot dwell with here – is that the presence of *feedback control loops* strongly relies on the structure within which material components are arranged. The last considerations add some other reason to maintain that, to properly understand experimental activity, top-down considerations are very important.

Conclusion

This paper is an attempt at understanding some essential interesting features of human experimental activity. After having made explicit some relevant point about experimental activity which are sometimes overlooked, it resulted that agency approach to causality gives interesting indications about what experiments actually are. Such an approach

[12]This point, although from a slightly different perspective, is also stressed in [Ellis, 2006b, 3.4.7]

to causality implies a certain enlargement of the causality notion scope, with respect to a strictly efficient causality. This enlargement makes possible the application of top-down mode of causality viewpoint to the experimental practice. In the last section some arguments both for the viability and the usefulness of this considerations have been presented. In this paper, experimental activity had been regarded in the most general way, without limiting oneself to a particular branch of physics. This led to take in account a rather weak notion of top-down causality, however, some of these branches may allow stronger versions. I am thinking to complexity theory and quantum mechanics. Each of these theories individuates a domain of reality, a sub-class of physical systems, which shows peculiar characteristics. Some of them result hardly understandable unless top-down mode of causality is seriously taken into account. I cannot extensively deal with such issues in the present paper; however, what I would like to stress is that here I endeavoured to consider experimental activity in its widest sense. I hope to dedicate other works to such special branches of physics; especially to quantum mechanics and its well known measurement problem.

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9

Analysis without Reductionism? Ernest Mayr and the Uniqueness of Biology

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The Peculiarities of a Discipline.

By the word "peculiarity" I do not intend something strange, exceptional or rare. The reference is to those distinguishing and essential features of a discipline whose researches are directed towards something, in turn, "peculiar" to the world around us: life. Considering the wide range of phenomena occurring in our planet which science tries to understand, life doesn't seem rare or unusual at all, not even marginal or exceptional. Life seems rather, through its various manifestations, something ordinary and constant from which is at least reasonable to expect regularities, deeply-rooted in the manifold we observe as conscious living beings, after all. Moreover, all living beings are in different ways, influenced and/or affected by external non-living matter, they share with it a certain basic constitution and they continually give rise to some changes on it by their actions. In other words, I'd like to suggest that it would be extremely hard to obtain a comprehensive, intelligible view of the phys-

ical world which surround us and in which we take part, without taking seriously into account the contribution of biology and the essential feature represented by the presence of life. That will ultimately require to contemplate those general features that seem preserved in every manifestation of it, distinguishing the living beings from all other realities, briefly, to drive the attention to what may be conceived as “peculiar” to life itself. Such a topic may correspond on the ontological level to the epistemological perspective adopted in this paper; it won’t be treated here explicitly but even so proposed as the intellectual horizon “peculiar”, in its turn, to the philosophy of biology.
By now, I only add that a serious reflection about life in itself will be also fruitful *just in order* to keep distance from any naïve and/or ideological kind of “vitalism”. As well-known, J. Monod was one of the strongest critics of vitalism within the framework of his “postulate of objectivity”. The statement about the marginality of biology placed at the beginning of his famous book (1970) is not totally in contrast with the considerations suggested above, since he regarded life as “rare” in relation to the wider scale of the universe as far as we know. But his criticism against vitalism was rooted in the assumption that we cannot derive any further objective-physical knowledge from the study of living beings. As pointed out by R. Rosen [Rosen, 2000], the emblematic opposite view may be recognized in E. Schrödinger’s essay *What is life?* [Schrödinger, 1988]: by studying organisms we can find the ground for building a “new physics”.
To these two extremely different positions we can add a third one according to which evolutionary biology based on Darwinian tradition can, as stated by D. Depew and B. Weber in an exhaustive critical essay [Depew and Weber, 1995], “expand its explanatory power by switching to a family of dynamic models associated with the study of complex systems, nonlinear dynamics, and chaos theory”. Complex systems’ approach has been theoretically and methodologically developed, as well as concretely adopted in relation to biological problems within an interdisciplinary framework by the founders and the members of the Santa Fe Institute (see for example [G. A. Cowan, 1994]). The actual and still topical epistemological problem concerning the relations between biology and physics will be outlined again in the following pages.

Considerations on a Remarkable Point of View.

Ernest Mayr, in one of his last publications [Mayr, 2004], draws his final conclusions about several important questions concerning evolution theories and philosophy of biology. Here we can find a sharp assessment:

any kind of reductionism is not compatible with the study of biological systems. Reductionism in general tells us that every phenomenon must be resolved in his constituent elements to be *completely and truly* explained. From an ontological perspective, all entities are nothing but the sum of their singular parts, and all regularities we can recognize in nature have to be considered as consequences of the operative laws pertaining the physical-chemical structure which underlies what we're observing. Therefore, going back to the epistemological level, reductionism maintains not only that is necessary to trace back phenomena to the *interactions* of their constituent micro-elements, but also that such a proceeding will be *sufficient* to exhaustively explain all kind of complexities showed by natural world; biology should be "reduced" to micro-physics, where "physics" is intended in the classical way, with its well-grounded, historically established, criteria of objectivity.
Now, many features peculiar to biological systems as Mayr also remarks, seem to disprove the claim to exhaustiveness of the mentioned approach, by simply not allowing its application: self-organization and feed-back controlled processes, acquiring, processing and storing of information through historical evolution, "open" informational programs not directly (or only partially) controlled by DNA, hierarchical structures where higher level properties are not ascribable to the lower level ones (about this last feature it is possible to speak in terms of "emergence" of characters and properties not predictable on the basis of the system's initial conditions nor having specified the system's components at a given time). It took hard work and quite a long time to show both the existence and the relevance of all these features, to conceive them as ordinarily belonging to the natural world, and it's still reasonable to think that we'll have to discover many more things about them and their implications.
For our present concerns, however, it could be useful to outlene the following issues. If the mentioned features peculiar to biological systems openly contrast the reductionism's approach, that does not imply that in biology analysis is forbidden. As again Mayr clearly remarks, analysis is the method through which we decompose a system *only as long as* such a proceeding provides new and useful data, and *without* claiming that the "smaller parts" or the lowest level elements are the only repository of all the answers we are looking for. The point here is not to renounce an undeniably fruitful method of investigation which is, among other things, often necessary to conceive and realize experiments. We cannot equate a dogmatic position (reductionism) to be rejected for scientific reasons, and a methodological approach (analysis) to be adopted in regards to some needs arising from the scientific research itself. In

this sense, it would be also quite superficial to distinguish biology from physics (or even from the "exact sciences") by saying that the former should or could not be "analytic".

Nevertheless, the mentioned features require models of explanation different from the "standard" one adopted by classical physics, *including* those features which are effective primarily at the molecular level. The problematic aspect usually remarked is the implication of a high degree of system's "unpredictability", so that even the possibility of achieving an objective knowledge about them has been (and still is) strongly discussed. A constructive challege may arise: maybe we'll have to wonder whether and to what extent the same criteria of determination, prediction and objectivity traditionally established in physics are to be reconsidered in regards to biological questions. Obviously a comprehensive discussion about the implications of such a crucial topic exceeds the limits af the present paper.

By now, I'd like to drive again the attention on the distinction between biology and physics, between the scientific study of living beings and physical sciences addressed to the non-living matter, by a further reference to Mayr's book of philosophy of biology.

In trying to justify the irreducibility of biology to any other physical science and to show the "uniqueness" of the former, he proceeds to what could be interpreted as an ontological generalization. Briefly, he maintains that unlike all the processes characterizing the non-living matter, biological processes are subject to a *double causation.* Here lies one of the clearest demarcation line, according to Mayr: biological processes (and only them) are both controlled by physical laws effective also in the non-living processes *and* by programs of information not even present and effective in any other kind of natural entities. These programs are broadly defined as codified or pre-organized information which control a process (or a behavior) leading it to a final state. It is precisely in this more general feature that has to be found the root of the "theleonomy" naturally showed by organisms, as well as the theoretical ground justifying the functional explanations recurring in biology.

Apart from the causality issue (which will be soon briefly reprised), we may note that the role played by programs of information can be considered crucial for the biological systems' peculiar features as mentioned above, and also for the general functions of any living organism.

Within this perspective, we can try to point out two relevant remarkable tasks for the theoretical biological research. One, is to clarify the integration of "closed" programs (that is, programs in which complete instructions are inscribed in the genotype's DNA) and "open" programs, which are structured in such a way as to allow the input and the consoli-

dation of new information acquired through the experiences of a lifetime. Clearly this task presupposes in-depth studies addressed to the mechanisms through which organisms acquire, process and transmit information. Moreover, the framework is, so to speak, enriched by Mayr himself, who already in a previous book [Mayr, 1988] pointed out the existence of "somatic" programs deriving from the neural central system, which are to be considered – like the "open" ones – only partially controlled by the genetic program, and turn out to be of extreme importance in relation to the dynamics involved in the ontogenesis of higher-level complex biological structures.
The other task is to account for the *origin* of programs of information. From both a philosophical and a scientific point of view, such an issue leads us to refer to the concrete constitution of these programs. Since we are trying to identify what brought about something, it could be useful to first address our efforts in trying to specify the actual nature of that "thing", or at least what should be considered the properties peculiar to it, in order to make clear to ourselves what is standing in front of us (and/or how it works), and then eventually distinguish the effect from the cause. If as mentioned before, programs of information should be seen for what is present and effective in living beings, for what in general is peculiar to them in comparison with non-living matter, then the question regarding their nature and their origin results deeply connected with the question about life itself (the recalled "Schrödinger's Question").
This last perspective is embraced, among others, by C. de Duve who, in its final wide-ranging book [de Duve, 2002], suggests that the answer to such a problematic question is actually very simple if we take a look to what all life forms (including human beings) have in common: life is information encoded in programs written in the same chemical language. Starting from that, we can formulate convincing theories about the original formation of the mechanisms which gave rise to life on earth, and even begin to plausibly reconstruct the features peculiar to the so called "L.U.C.A." (*Last Universal Common Ancestor*) by analyzing the basic chemical constitution of its descendants. De Duve underlines the progresses achieved by molecular and cellular biology, showing a quite enthusiastic attitude by saying that in present times to affirm that we know the "secret of life" is not an overstatement.
Mayr, on his side, appears to be more cautious and vague about the point. He remarks that we still do not know sufficiently the genetic-molecular basis of the programs of information, particularly of those which should account for the realization of the general morphogenic process, and therefore we cannot establish to what extent they should

be considered as congenital. Nevertheless, he clearly states that in theory all the processes of theleonomy can be reduced to chemical-physical causes. He also seems to finally maintain that the programs of information in which should be seen the final causes affecting living beings (and only them) are the result of past efficient causes that acted during the past evolutional history of organisms. Such assessments are worth stressing because they could from a certain point of view, invalidate the critic against reductionism carried out by the author himself. Maybe according to our present knowledge, we cannot i*n principle exclude* that the life's enigma could be solved turning on simple chemical-physical mechanisms and processes. Anyway, one point I would like to show with care in the future is that, even in such a possibility, biology cannot *in principle be reduced* to classical-intended physics and chemistry depending on strong epistemological requirements; for instance, the "context relevance" which appears totally in contrast with the classical identification of scientific objectivity as context-independence [Rosen, 2000], and the connected importance assumed by the constraints which move into the center of the explanation and thus themselves become a part of the explanandum [Küppers, 1990]. Any analytical approach to biological phenomena should hold in due consideration such peculiar requirements.

Part III

Conclusions

I Workshop on The Relationship between Science and Philosophy: New Opportunities for a Fruitful Dialogue

Domus Sanctae Marthae
April 7-8, 2006
Vatican City

In the Vatican 7 to 8 April 2006, under the high Patronage of the Pontifical Council for Culture and with a grant of the John Templeton Foundation, a workshop was held organized by the Specialization Science and Philosophy of the Pontifical Gregorian University on the theme the "Relationship between Science and Philosophy: New Opportunities for a Fruitful Dialogue". The discussion focused on many contentious issues.

(1) The first was the character of the relations between science and philosophy. Medieval philosophers had conceived of this relation in terms of an inferential chain such that, moving from the first and more general principles of philosophical nature, the scientific issues, or at least the issues concerning a specific area of knowledge, were framed in that general context and came to constitute specific applications of those principles. To this continuist vision the modern ages have opposed a discontinuist view, according to which science is based on autonomous principles able to determine a specific domain of investigation. The connection with general principles is here considered as extraneous to the scientific enterprise and even in contradiction with its meaning, since its task is to

obtain specific results that are empirically verifiable. This gap between science and philosophy led Kant to postulate a strict partition between a mechanist physical science together with a Euclidean geometry on the one hand, and a metaphysics, based on a moral urge, on the other hand. While the former was cumulative and did thus represent true forms of knowledge, metaphysics had, as object, problems that were destined to be cognitively unsolvable. During the 20th century, after some important results obtained in the previous century, a change of paradigm began to impose itself. The emergence of new problems and new scientific areas, in particular quantum mechanics, cosmology, non-linear thermodynamics, molecular biology, together with some formal results in mathematics and logic, like Gödel's and Löwenheim-Skolem's theorems, have provoked a crisis in the scientific certitudes that were basic for several scientific areas, and therefore necessarily opened the way for examining the foundations of scientific knowledge and also, in an epistemological and historical context, the legitimacy of the methodologies and assumptions defining several disciplines. In this way, philosophy has developed an important reflection about science, and the autarchic closure of the latter has reached its end. Moreover, this philosophical reflection represents considerable epistemological progress, showing that philosophy may also progress. Moreover, in some specific domains, such as quantum mechanics, it has become increasingly evident that philosophical principles play a more active role than was previously imagined. In particular, as is the case for the reality principle proposed in 1935 by Einstein and co-workers, even if such principles are devoid of direct empirical and scientific relevance as such, they, in connection with additional assumption of a scientific nature, can imply previsions that are testable and therefore have empirical meaning. In such a way, while philosophy can participate, in a top-down direction, to the scientific debate, it is also true the converse, that is, that, in a bottom-up flux, scientific results contribute to determine the domains and the forms in which philosophy does its work. For this reason, philosophy acquires an inductive and abductive flavour able to characterize its style and its choice of the problems in a new way. Such a confrontation can avoid two dangers that are always present in the confrontation between science and philosophy: the first is the tendency to build a metaphysics starting from specific scientific problems, the second is to build a system of the world that does not consider scientific results about the world.

(2) Closely related to the previous issue is the nature of explanations, a subject that is simultaneously scientific and philosophical. In the middle ages a methodology of causal explanations was established.

From this point of view, modern science represents a heritage of scholasticism. However, modern science fully rejected final causes and adopted efficient causation as the tool of explanation, which was later determined as mechanical causation. Such a paradigm became predominating in the course of centuries up to the point in which it was identified with the concept of scientific explanation as such. Obviously, final causes have still played a role in the context of practical or even human sciences. This could be the ultimate reason for the dichotomy between the so-called two cultures. During the 20th century the evidence that this paradigm, even in the framework of natural sciences, could not allow for explanation of vast areas of knowledge, in particular that it could not work for quantum-mechanical, complex, and biological systems, gradually imposed itself. In all these cases a new situation arises. The evolution of classical-mechanical systems is strictly and univocally determined by the initial conditions of the system. A change of these conditions will in general produce a proportional change in the trajectory (in the configuration or phase space) of the system. In any case, the final state of the system is a consequence of the initial conditions. Quantum-mechanical systems and many complex and biological systems do not have a univocal final state, given certain initial conditions. Rather, there are many possible alternative features, which characterize the same system, given the same initial conditions. Moreover, in the case of biological systems, especially during epigenesis, the organism can arrive essentially to the same ripe form through different paths and in presence of very different environmental stimuli, but which are considered equivalent from the point of view of the organism's development. These equivalence classes are what makes impossible a mechanical explanation of traditional type, which is necessarily centred on the description of a single system and a single trajectory. Here, on the contrary, the explanation has a class of behaviours or of equivalent states as its object, and presents therefore from the start a rather general character. The interest of such explanation is that it is neutral relative to mechanist and teleological explanations. Even if it is possible to find, probably in some cases, a mechanical explanation of similar situations, this type of explanation does not exclude that there could be present some teleological or teleonomic aspects. Indeed, as it was understood by the philosopher Charles Peirce, causal ends are exactly characterized by the fact that, relative to a certain end, there is an equivalence class of means or paths for obtaining it. This feature is closely related with the problem of emergence. Complex systems and biological organisms show properties that do not seem reducible to the properties, often of mechanical type, of the atoms and molecules that compose them. Also here, emergence is closely related with the fact that the global behaviours of the system under consideration are organized in equivalence classes, such that the behaviour of the parts is not able to determine a single behaviour of the whole. The concept of emergence forces us to reconsider physical and biological systems as open to the environment, and to consider dynamics as a dynamics of open systems in which both local and global features are interwoven.

(3) The concept of emergence raises one of the most difficult scientific and philosophical problems of the 21st century: the issue of the mind-body problem, or at least of the mind-brain relation. At a more general level, that is, at a purely philosophical level, it raises the problem of the philosophy of *natural beings*, where with natural being we understand: (a) finite beings, and (b) beings that are part of the universe we can observe or at least of which it is possible to have, directly or indirectly, some experience. The philosophical task is here to individuate properties and features that are common to all natural beings. As is well known, while the Middle Ages assumed that the union of matter and form are the most specific character of natural beings, modern science has tried to reduce the material being to some mechanical combination of its material elements. Also here the 20th century has changed many certitudes. However, much work remains to be done and, due to the difficulties of the problems, we are obliged to proceed in a spot-like way. In particular, two concepts seem here to be of high interest. The first is that of *information.* Landauer and Bennet's theorem in information theory shows that is possible to process information without energy expenditure, provided that one does not select information. This suggests the possibility of considering information as a datum that is more basic than energy or other physical quantities. Moreover, recent studies in quantum mechanics show that quantum systems can share information without exchanging physical signals. This suggests the possibility of considering information as a quantity that is not connected by a physical support in the traditional sense of the word, and opens therefore the possibility for developing some general ontological considerations about the nature of the physical being. Indeed, if information is a kind of interface between physical and mental worlds, one could maybe avoid a form of direct action of the mind on the physical world (which would be unintelligible if it were to represent a violation of the closure of physical laws) as well as any unintelligible action of the physical world on the mind (which would remain inexplicable in a dualistic scheme). In this way, mind and physical world could be relatively independent but share notwithstanding some information that enables the mind to autonomously decide but also to translate its decisions in phys-

ical action through physical means. Another important concept is that of *network*. Also this concept has a wide domain of applicability (from physical systems up to social, artificial and even mathematical systems) and presents an interesting connection with both the concept of emergence (and of self-organization) and of information. Indeed, quantum mechanics, showing that one can share information without signal exchanging, allows for the interesting possibility of considering any form of relation or interdependency (which are pivotal for networks) as a type of mutual information.

(4) Philosophy has a universal aspiration. However, since human beings are not omniscient, such aspiration is necessarily expressed from a particular point of view. This justifies to a certain extent that there are many philosophical schools and orientations. It is difficult to be faithful to the universal exigency of philosophy without confronting the empirical sciences. The domain of such a philosophy comprehends necessarily the above three great directions. It must contain a reflection on science and its methods, that is, it must integrate a philosophy of science in a narrow sense. Then, it must deal with the most universal problem of the conditions of possibility of knowledge in general and of scientific knowledge in particular, which is a problem transcending the issue of the explanations and methodologies employed in the proper scientific enquiry, and come to touch problems that are simultaneously about knowledge as such and the foundations of any scientific knowledge. Finally, it must also consist of a philosophy of natural beings. It is typical of a philosophical enterprise that these three features cannot be separated, and rather must be developed in strict interconnection and interaction.

The workshop's organizers hope that such an initiative could become permanent, with an annual meeting, and contribute to throw light on these issues.

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